SN

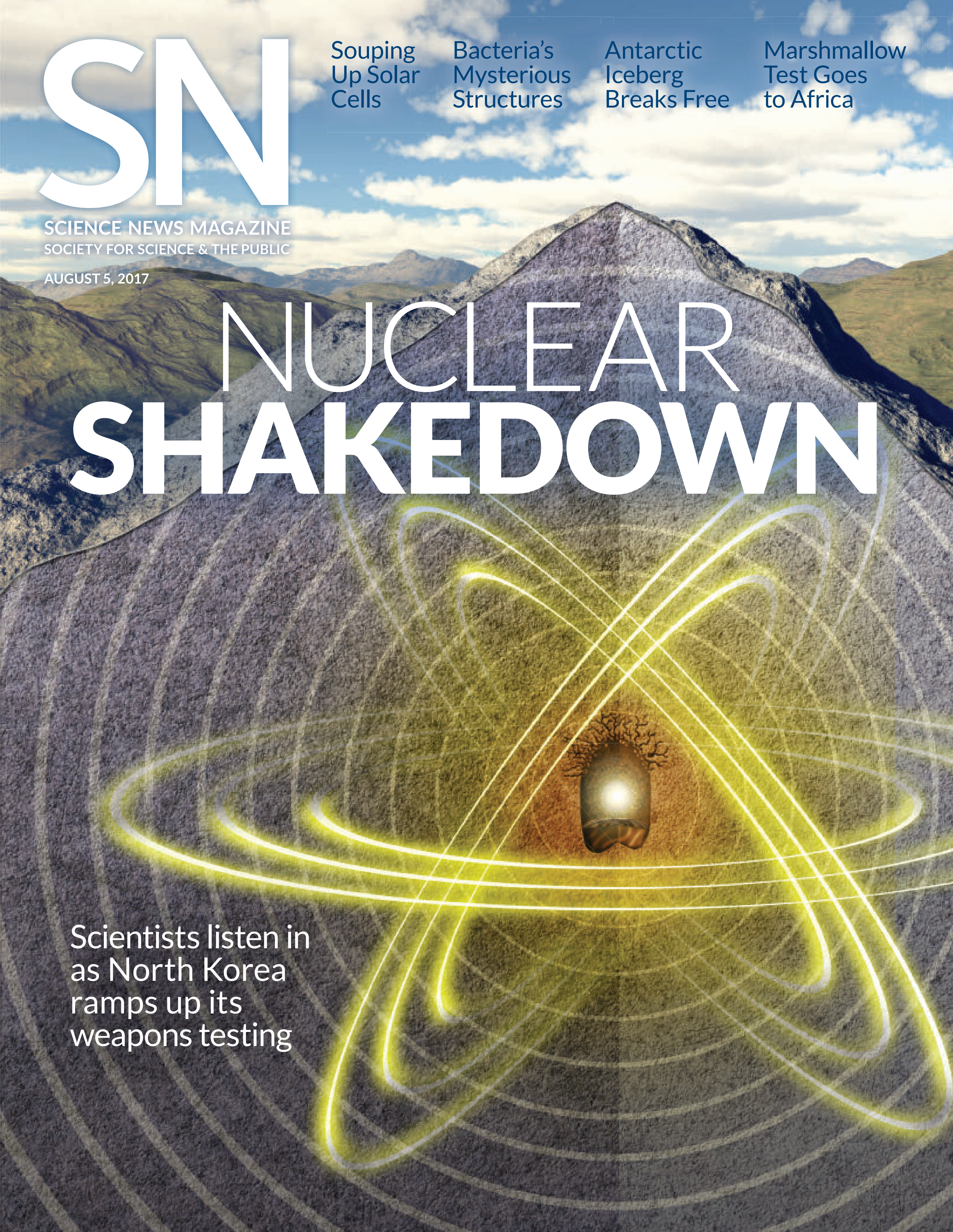
SCIENCE NEWS MAGAZINE
SOCIETY FOR SCIENCE & THE PUBLIC
AUGUST 5, 2017

Souping Up Solar Cells

Bacteria's Mysterious Structures

Antarctic Iceberg Breaks Free

Marshmallow Test Goes to Africa

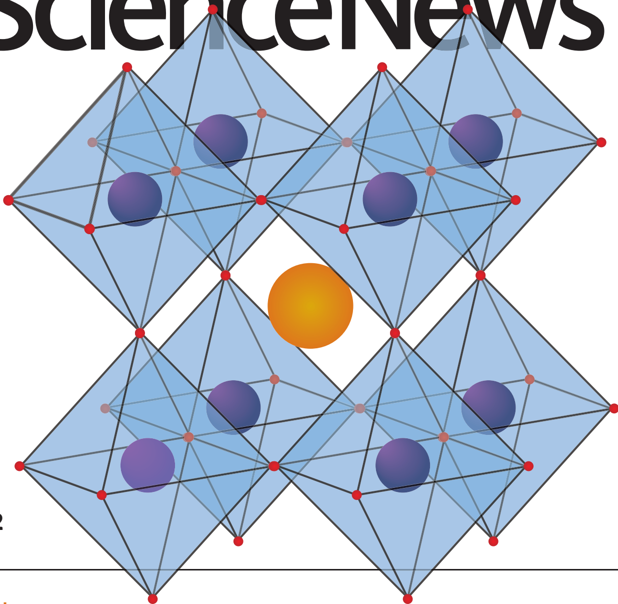


NUCLEAR SHAKEDOWN

Scientists listen in as North Korea ramps up its weapons testing

VOL. 192 | NO. 1

Science News

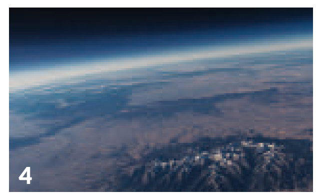


22

Features

News

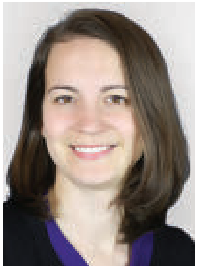
10



4

Departments

COVER Rumblings of seismic waves reveal clues about North Korea's nuclear weapons tests, detonated in a mountain. *Nicolle Rager Fuller*



Expert eavesdroppers occasionally catch a break

In July of 1972, NASA launched the first Landsat satellite into orbit around Earth. Since then, the spacecraft and its successors have transformed our understanding of Antarctica (and the rest of the planet, too). In the first year following the launch, Landsat's images of the faraway continent showed "uncharted mountain ranges, vast ice movements and errors in maps as little as two years old," according to an article published in *Science News*. William MacDonald of the U.S. Geological Survey, who had spent eight years mapping a part of West Antarctica, was "shocked" to learn of previously unknown peaks just 100 miles from McMurdo Station.

Landsat's images weren't the first overhead shots of Antarctica, but to this day the program provides researchers a reliable and repeating view of hard-to-reach corners of the planet. It was Landsat images that in November of 2014 first alerted scientists to a growing crack in the Larsen C ice shelf that, after lengthening by about 20 kilometers in less than nine months, threatened to break off a Delaware-sized chunk of the shelf. With thermal imagery from Landsat 8 along with data from the European Space Agency's Sentinel-1 satellites, scientists sitting half a world away tracked the Larsen C crack to its final break, as described by Ashley Yeager on Page 6.

While satellites are scientists' eyes in the skies, seismic sensors serve as ears to the ground. On Page 18, Alexandra Witze describes the work of scientists who are using seismic sensors to monitor nuclear weapons activity in a part of the planet where access to information is limited: North Korea. Five nuclear weapons tests have been confirmed in the country since 2006, all at an underground test site in Mount Mantap. By tracking seismic waves produced by such explosions, and comparing these rumbles with each other and with those produced by natural earthquakes and in experimental tests, researchers around the world gain valuable clues to where the hidden explosions are happening and, importantly, how powerful they are. A North Korea weapons test last year was detected as far away as Bolivia.

The art of eavesdropping certainly has its rewards. There are plenty more examples. On Page 10, Rachel Ehrenberg writes about how snooping scientists might listen in on kelp to predict ecosystem health. And on Page 7, Emily Conover reports on a newly discovered, relatively itty-bitty star some 600 light-years away. Astronomers spied on the star by watching it pass in front of a larger star, dimming the larger star's light.

Sometimes astronomers get lucky and distant phenomena are much more straightforward to study. That will be the case later this month when a total solar eclipse passes across North America from Oregon to South Carolina. People will be monitoring the August 21 eclipse in all sorts of ways, including via a livestream from balloons at the edge of the atmosphere, as Lisa Grossman describes on Page 4. Grossman will be reporting on the eclipse on the ground with scientists in Wyoming. You'll find her stories — along with many others about the ways scientists watch, listen and learn — at sciencenews.org.

— Elizabeth Quill, Acting Editor in Chief

PUBLISHER Maya Ajmera
ACTING EDITOR IN CHIEF Elizabeth Quill

EDITORIAL
NEWS DIRECTOR Macon Morehouse
DIGITAL DIRECTOR Kate Travis
FEATURES EDITOR Cori Vanchieri
MANAGING EDITOR, MAGAZINE Erin Wayman
ASSOCIATE EDITORS Emily DeMarco, Cassie Martin
WEB PRODUCER Helen Thompson
AUDIENCE ENGAGEMENT EDITOR Mike Denison
ASTRONOMY Lisa Grossman
BEHAVIORAL SCIENCES Bruce Bower
BIOMEDICAL Aimee Cunningham
LIFE SCIENCES Susan Milius
MOLECULAR BIOLOGY, SENIOR WRITER Tina Hesman Saey
PHYSICS Emily Conover
STAFF WRITER Laurel Hamers
SCIENCE WRITER INTERN Maria Temming
EDITOR AT LARGE Tom Siegfried
CONTRIBUTING CORRESPONDENTS
Laura Beil, Susan Gaidos, Alexandra Witze

DESIGN
CHIEF DESIGN OFFICER Stephen Egts
DESIGN DIRECTOR Erin Otwell
ART DIRECTORS Justine Hirshfeld, Molly Telfer
GRAPHIC DESIGNER Tracee Tibbitts

SCIENCE NEWS FOR STUDENTS
EDITOR Janet Raloff
MANAGING EDITOR Sarah Zielinski
SCIENCE EDUCATION WRITER Bethany Brookshire
WEB PRODUCER Lillian Steenblik Hwang

SOCIETY FOR SCIENCE & THE PUBLIC
PRESIDENT AND CEO Maya Ajmera
CHIEF OF STAFF Rachel Goldman Alper
CHIEF MARKETING OFFICER Kathlene Collins
CHIEF FINANCIAL OFFICER Charlie Feeney
CHIEF PROGRAM OFFICER Michele Glidden
CHIEF, EVENTS AND OPERATIONS Cait Goldberg
CHIEF COMMUNICATIONS OFFICER Gayle Kansagor
CHIEF ADVANCEMENT OFFICER Bruce B. Makous
CHIEF TECHNOLOGY OFFICER James C. Moore

ADVERTISING AND SUBSCRIBER SERVICES
ADVERTISING Daryl Anderson
SUBSCRIBER AND MEMBER SERVICES Kerwin Wilson
SCIENCE NEWS IN HIGH SCHOOLS Anna Rhymes
PERMISSIONS Evora Swoopes

Science News
1719 N Street NW, Washington, DC 20036
(202) 785-2255

Subscriber services:
E-mail member@societyforscience.org
Phone (800) 552-4412 in the U.S. or (570) 567-1191 outside of the U.S.
Web www.sciencenews.org/join
For renewals, www.sciencenews.org/renew
Mail *Science News*, PO Box 1205, Williamsport, PA 17703-1205

Alliance for Audited Media

Editorial/Letters: editors@sciencenews.org
***Science News* in High Schools:** snhs@societyforscience.org
Advertising/Sponsor content: ads@societyforscience.org
Science News (ISSN 0036-8423) is published biweekly by Society for Science & the Public, 1719 N Street, NW, Washington, DC 20036.
Online and tablet access: Activate your subscribing member account, including digital access and the ability to opt out of print, at www.sciencenews.org/activate
Subscribing memberships include 24 issues of *Science News* and are available for $50 for one year, published biweekly except monthly in January and July (international rate of $68 includes extra shipping charge).
Single copies are $3.99 (plus $1.01 shipping and handling).
Preferred periodicals postage paid at Washington, D.C., and an additional mailing office.
Postmaster: Send address changes to *Science News*, PO Box 1205, Williamsport, PA 17703-1205. Two to four weeks' notice is required. Old and new addresses, including zip codes, must be provided.

SSP

Excerpt from the August 12, 1967 issue of *Science News*

50 YEARS AGO

Hope from diabetic mice

[Millions of diabetics] could be indebted to a strain of diabetic mice being bred in Bar Harbor, Maine. In diabetes research, "this mouse is the best working model to date," one of its discoverers, Dr. Katharine P. Hummel, says.... A satisfactory animal subject had eluded diabetes researchers, until the mouse was found.

UPDATE: Hummel's diabetic mice are still used in research to mimic type 2 diabetes in humans, which is linked to obesity. In the mid-1990s, researchers found that the diabetic mice carry a mutation in the leptin receptor gene, which prevents the hormone leptin from signaling fullness and triggering other metabolic processes. In people, however, the disease is more complicated. More than 40 genetic variants are associated with susceptibility to type 2 diabetes. Unlike the mouse mutation, none of those variants guarantee a person will develop the disease.

The edge of the atmosphere over the mountains of Idaho and Montana is visible from a test balloon. Video of the upcoming total solar eclipse will come from a fleet of similar balloons.

THE SCIENCE LIFE

All eyes on the eclipse

Only a lucky few have watched a solar eclipse from above the Earth. Angela Des Jardins wants to bring that view to everyone.

On August 21, Des Jardins, an astrophysicist at Montana State University in Bozeman, will help broadcast the first livestream of a total solar eclipse from the edge of space. She and more than 50 groups across the United States will launch high-altitude balloons to film the moon's shadow racing across the Earth and broadcast it over the internet as it happens (eclipse.stream.live).

"On the ground, an eclipse just kind of happens to you. It just gets dark," says Des Jardins. "From the air, you can see it coming and going. I think that perspective is really profound."

Des Jardins got the idea from a news story about a pilot who flew his plane into the path of an eclipse over the Atlantic Ocean in 2013. Her group engineers high-altitude balloons to study everything from ozone to high-energy particles produced in thunderstorms. She figured it would be easy to fly cameras on the balloons and get beautiful footage. She knew it could be done; another group had filmed an eclipse from a balloon in Australia in 2012.

Students practice launching balloons like the ones that will loft cameras to livestream the solar eclipse on August 21.

But in a cynical moment, she wondered if anyone would watch video of an eclipse after the event.

"I was thinking about living in this age of needing to be there, in the moment, or we don't care," she says. "To really have an impact, I knew it needed to be live."

Suddenly the project was much more interesting. Now the balloons needed to carry GPS antennas for tracking and satellite modems to transmit images and video, plus microcomputers to manage it all. The inflatables needed space for other scientific equipment, too. And a balloon with all those components had to weigh less than 12 pounds to meet Federal Aviation Administration rules. NASA got involved, as did colleges and high schools across the country. Some of the students involved in the project are now getting jobs with groups like aerospace company Lockheed Martin and space tourism company World View.

When the total eclipse starts at 10:15 a.m. Pacific time on August 21, Des Jardins will be at a small airport in Rexburg, Idaho, tracking four 2.5-meter-tall balloons as they float up to 30 kilometers above the Tetons.

She'll also be live chatting with more than 50 teams from Oregon to South Carolina — professional scientists, high school and university students, and amateur astronomy clubs. She hopes the videos will help more people personally experience how the Earth, moon and sun move around each other, linking our hyperconnected world to its cosmic context. — *Lisa Grossman*

BOTH: KELLY GORHAM/MONTANA STATE UNIV.

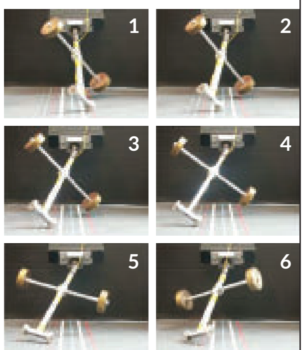
FOR DAILY USE

What makes your wheelie wobble

Roller luggage has a way of fishtailing. For most travelers, this is a nuisance. For a few scientists, it's a physics problem they solved in a study published in the June *Proceedings of the Royal Society A*.

The researchers simulated and observed the motion of a toy model suitcase on a treadmill. The suitcase's side-to-side motion at any given moment, they found, is related to its left-to-right tilt and distance off-center from the line of travel.

Imagine a suitcase rolling straight ahead, then hitting a bump or cutting a corner, causing the left wheel to lift. The suitcase's tilt makes the right wheel steer the case leftward. When the left wheel falls back to the ground and the right wheel lifts off, the suitcase — now positioned and tilted to the left — banks right. Switch wheels, swing, repeat.



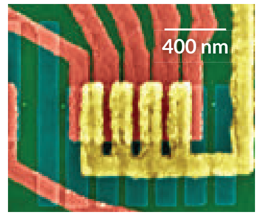
As a model suitcase cuts a corner (wheels at front) the left wheel lifts (1), so the right wheel steers the case leftward (panels 2–4). As the left wheel reconnects with the floor, the right wheel lifts, and the case banks right (5–6).

This swaying motion actually gets smaller when the suitcase rolls faster, says study coauthor Sylvain Courrech du Pont. Lowering the angle of the suitcase can stop the rocking altogether.

The physics of this system also applies to other two-wheel carriers — like car-pulled trailers. "In the near future, maybe we will have a car without a driver," says Courrech du Pont, a physicist at Paris Diderot University. "It would be a good thing if the car knows how to stop this kind of motion." *— Maria Temming*

THE -EST

World's tiniest transistor



Four itty-bitty transistors sit between barriers (blue). Current flows through electrodes (red). Gates (yellow) turn current on and off.

Carbon nanotubes may be the key to shrinking down transistors and squeezing more computer power into less space. Historically, the number of transistors that can be crammed onto a computer chip has doubled every two years or so, a trend known as Moore's law. But that rule seems to be nearing its limit: Today's silicon transistors can't get much smaller than they already are.

Carbon nanotubes may offer a sizable solution. In the June 30 *Science*, IBM researchers report a carbon-nanotube transistor with an overall width of 40 nanometers — the smallest ever. It's about half the size of typical silicon transistors.

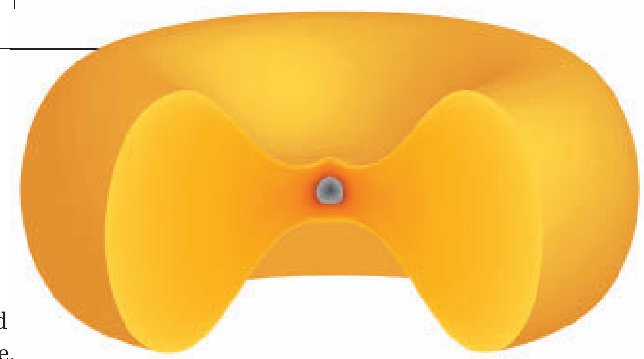
Researchers have created carbon-nanotube transistors with certain supersmall components before, but the whole package was still bulky, says study coauthor Qing Cao of IBM's Thomas J. Watson Research Center in Yorktown Heights, N.Y. The new study confirms that, in terms of size, carbon-nanotube transistors can beat out silicon — and that's no small feat. *— Emily Conover*

SAY WHAT?

Synestia \sin-ES-ti-ə\ n.

A large spinning hunk of hot, vaporized rock that forms when rocky, planet-sized objects collide

Earth may have taken on a jelly doughnut shape early in its history. The rocky planet was spinning through space about 4.5 billion years ago when it smacked into a Mars-sized hunk of rotating rock called Theia, according to one theory (*SN: 4/15/17, p. 18*). That hit may have turned Earth into a synestia, a blob of mostly vaporized rock with an indented center, resembling a slightly squished jelly doughnut, new simulations suggest. This synestia wouldn't have had much of a solid or liquid surface. And the structure could have spread to about 100,000 kilometers across or more, much larger than its original 13,000 kilometers or so. The added girth would have come from rock vaporizing and continuing to spin quickly, which would puff up and flatten the shape.


Early in its development, a rocky planet may turn into a synestia (illustrated), a spinning disk of vaporized rock that looks like a jelly-filled doughnut with a small, solid core (gray).

If Earth went through a synestia state, it was short-lived. An object Earth's size would have quickly cooled and condensed back into a solid, spherical rock in 100 to 1,000 years, researchers write online May 22 in the *Journal of Geophysical Research: Planets*. Rocky bodies may become synestias several times before settling into a permanent planet shape, say planetary scientists Simon Lock of Harvard University and Sarah Stewart of the University of California, Davis. They came up with the term *synestia* from syn-, meaning together, and Hestia, the Greek goddess of home, hearth and architecture.

No one has seen a synestia in space. But the weird structures could be out there, waiting to be discovered in solar systems far away. *— Ashley Yeager*

FROM TOP: IBM; G. FACCHINI, K. SEKIMOTO AND S. COURRECH DU PONT/*PROC. ROYAL SOC. A* 2017; S. LOCK/HARVARD UNIV.

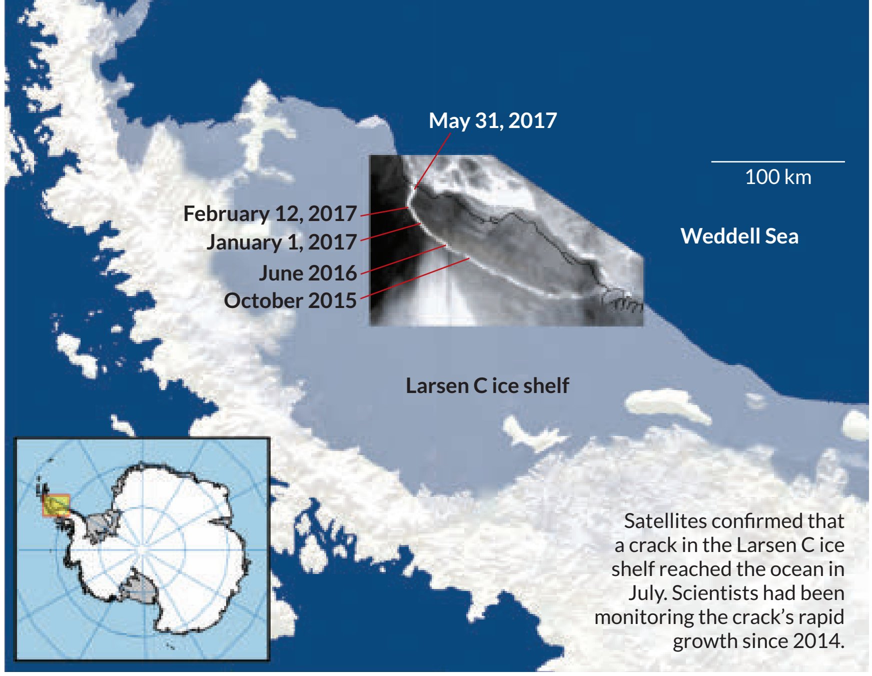
News

EARTH & ENVIRONMENT

Giant Antarctic iceberg splits off

Calving event raises questions about stability of Larsen C

BY ASHLEY YEAGER



Satellites confirmed that a crack in the Larsen C ice shelf reached the ocean in July. Scientists had been monitoring the crack's rapid growth since 2014.

PROJECT MIDAS, A. LUCKMAN/SWANSEA UNIV. ADAPTED BY T. TIBBITTS

With a final rip, an iceberg roughly the size of Delaware has broken off Antarctica's Larsen C ice shelf. Expected for weeks, the fracture is one of the largest calving events ever recorded.

On July 12, satellite images confirmed a nearly 5,800-square-kilometer, 1-trillion-metric-ton chunk of ice — more than 12 percent of the ice shelf's total area — split from Larsen C. "[We] have been surprised how long it took for the rift to break through the final few kilometers of ice," Adrian Luckman, a glaciologist at Swansea University in Wales, wrote in a blogpost for Project MIDAS, which has been tracking the effects of a warming climate on the ice shelf. Now the focus will shift to the ice shelf's stability and the giant iceberg's fate.

Scientists had been monitoring Larsen C since 2014, when they noticed that a crack in the ice shelf had grown about 20 kilometers in less than nine months (*SN: 7/25/15, p. 8*). After a relative lull in 2015, the crack grew 40 kilometers in 2016 and then 10 more in the first half of January 2017, bringing its length to 175 kilometers.

The crack then grew 17 kilometers between May 25 and May 31, at times traveling parallel to the edge and ultimately putting it within 13 kilometers of the ice front. In late June, the outer part of the ice shelf picked up speed, putting new pressure on the crack and the entire shelf. "We can't claim iceberg calving yet, but it won't be long now," Project MIDAS tweeted June 30.

Yet the vigil lasted nearly two more weeks. By July 6, the crack had come within five kilometers of the edge of the ice. Then, sometime between July 10 and July 12, it finally reached the water, and the hunk of ice splintered off into the Weddell Sea.

The ice loss dramatically alters the landscape, Luckman notes: "Maps will need to be redrawn." And that could be the least of the trouble ahead, says Adam Booth, a geophysicist at the University of Leeds in England also with Project MIDAS. "The calving event is significant because it is likely a precursor to something much bigger, potentially the collapse of the whole Larsen C ice shelf." The same thing happened to the neighboring Larsen B ice shelf in 2002, after it calved a Rhode Island–sized iceberg.

"Glaciologists are keen to see how Larsen C will react," Luckman says.

A complete collapse of Larsen C could have implications for sea level rise. Ice shelves act as buttresses, helping to slow the flow of Antarctica's ice into the ocean. Since these shelves float on the water, calving doesn't directly raise sea level. But calving or the collapse of an ice shelf allows glaciers and ice streams farther inland to flow into the ocean, which can contribute to sea level rise.

Calving is common, and over several decades, ice shelves usually recover to their original size. But in the last two decades, shelves have instead continued to lose ice until collapsing, probably as a result of warming due to climate change, researchers suspect. In 2014, scientists concluded Larsen B's collapse was the result of warming (*SN: 10/18/14, p. 9*).

Some computer simulations suggest Larsen C could suffer the same fate, possibly within a few years to decades, says Luckman. Still, the calving event that feeds a potential collapse may be hard to pin on climate change. "Not all ice-related stories have a clear global warming origin," Luckman notes. Larsen C's calving, he says, "may simply be a natural event that would have happened regardless of human activity."

Not everyone is convinced that Larsen C will fall apart completely. Researchers in Europe predict major changes to the shelf would happen only if it loses 55 percent of its ice. At that point, a significant amount of ice could ooze from glaciers into the ocean. Still, understanding what allowed the recent rift to grow and calve will "give us insight regarding other fractures or rifts on the shelf," says geoscientist Dan McGrath of Colorado State University in Fort Collins. While McGrath says a collapse is "very unlikely," he adds that "other dormant rifts are in locations where if they reinitiated, the subsequent calving event would be worrisome."

Booth acknowledges that Larsen C is just a small part of Antarctica. But, he says, "What is worrying is that we're seeing trends in several ice shelves that tend towards decreasing stability. Should they continue along these trends, we could be seeing the start of increased mass loss from the Antarctic continent." ■

ATOM & COSMOS

Metallic air may have swaddled moon

Vaporized magma created short-lived atmosphere, scientists say

BY LISA GROSSMAN

The infant moon may have had a thick metal atmosphere, with supersonic winds that raised waves from its magma ocean.

That's the conclusion of a simulation that calculates how heat from the young sun, the Earth and the moon's own hot surface could have vaporized lunar metals to give the moon an atmosphere as thick as that of Mars. The model, reported online June 22 at arXiv.org, offers a way to test theories of how the moon formed.

Most scientists think the moon formed when a Mars-sized protoplanet hit Earth about 4.5 billion years ago (*SN: 4/15/17, p. 18*). The collision threw hot, molten material into Earth's orbit, which coalesced and later cooled into the moon.

In its early days, though, the moon would have been covered in a deep, global ocean of hot liquid rock. The postcollision Earth would have been blisteringly hot as well — upwards of 2000° Celsius — and would have glowed like a red dwarf star.

Prabal Saxena of NASA's Goddard Spaceflight Center in Greenbelt, Md., and colleagues added up the radiation the early moon would have received from that starlike Earth, plus from the sun and the magma ocean itself. Previous models had suggested the early moon should have an atmosphere, but the team says its model is the first to include all those inputs at once, revealing fresh details about how the atmosphere and ocean may have interacted.

All of that radiation would have vaporized volatile elements in the metal-rich magma ocean and formed an atmosphere about one-tenth the thickness of Earth's, the model showed. To keep things simple, the team used sodium — an easily vaporized element that is abundant on the moon — to represent all the components that could contribute to an atmosphere.

As long as the molten ocean remained liquid, the atmosphere would have received freshly vaporized sodium from the ocean and sent the sodium whipping upward. An extreme temperature difference — the side of the moon facing Earth would have been heated to more than 1700° and the farside would have been chilled to about –150° — would have raised winds with speeds over a kilometer per second. The winds would probably have blown waves in the magma ocean.

When the winds reached the twilight zone between hot and cold, the atmosphere would have condensed, leaving a band of sodium snow.

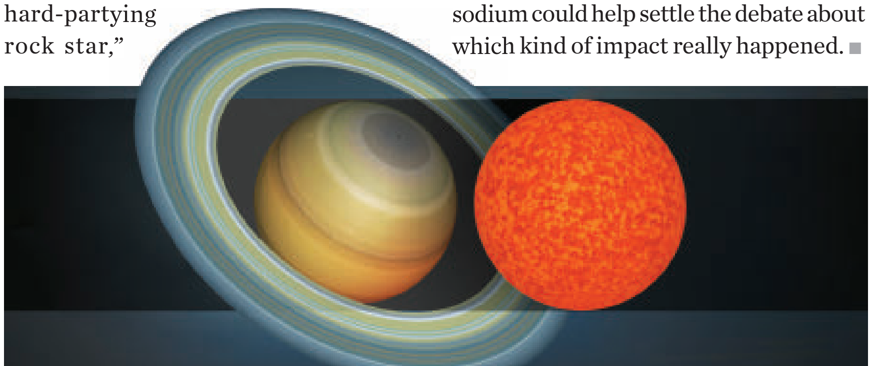
After about 1,000 years, the moon's magma ocean would have cooled enough to solidify into a rocky crust. Without liquid to draw from, the entire atmosphere would have collapsed.

"The moon's atmosphere was like a hard-partying rock star," Saxena says. "It had a really violent, heavy metal existence, but it rapidly just fell apart."

Kevin Zahnle of NASA's Ames Research Center in Moffett Field, Calif., says this live fast, die young picture of the atmosphere sounds plausible and may be testable. But he's not sure all of the model's assumptions are good. The Earth and the moon would have had to be "exceedingly dry" to avoid developing steamy water atmospheres first, for instance.

One way to test the model would be to look for a ring of extra sodium in the rocks around the moon's twilight zone. That would show that the atmosphere really did have an extreme temperature gradient and high winds.

Other models of the moon's formation — for example, if it formed from several small impacts — would lead to a cooler atmosphere, weaker winds and no sodium snow, Saxena says. Finding extra sodium could help settle the debate about which kind of impact really happened. ■



COURTESY OF UNIV. OF CAMBRIDGE

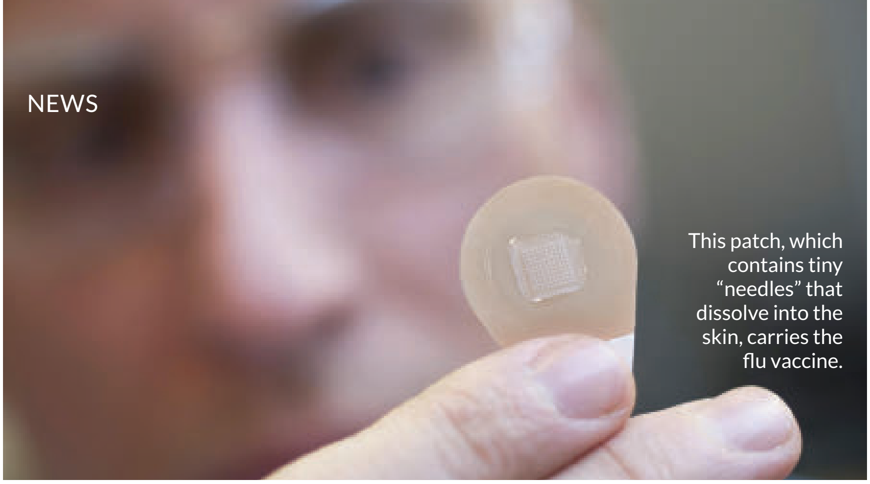
ATOM & COSMOS

Teensy star vies for title of smallest known

A teeny-weeny star, with a radius about the size of Saturn's, is one of the smallest ever found. Known as EBLM J0555-57Ab, the star (illustrated next to Saturn) is significantly smaller than the Jupiter-sized TRAPPIST-1, a peewee star famous for hosting a septet of Earth-sized planets (*SN: 3/5/17, p. 6*). And the newfound star is comparable in size to a previously reported runt, 2MASS J0523-1403.

Although the newfound star's girth is similar to Saturn's, it is much heftier, at almost 300 times Saturn's mass. Still, that's only about 8 percent of the sun's mass, meaning that the star barely meets the qualifications for joining the stellar ranks, scientists report in an upcoming issue of *Astronomy & Astrophysics*. The star is just at the limit at which nuclear fusion can occur in a stellar core. If the star were less massive, it would instead be a failed star known as a brown dwarf.

The miniature star orbits another, larger star some 600 light-years away. Scientists with the Wide Angle Search for Planets, or WASP, collaboration detected the star with a method typically used to scout out exoplanets: watching it pass in front of its companion and dim the larger star's light. *— Emily Conover*



This patch, which contains tiny "needles" that dissolve into the skin, carries the flu vaccine.

BODY & BRAIN

Patch could someday replace flu shot

Vaccine-infused microneedles prompted immune response

BY AIMEE CUNNINGHAM

DIY vaccination may be on its way. In the first test in adults, a Band-Aid–like patch studded with dissolving microneedles safely and effectively delivered a dose of influenza vaccine.

People using the patch had a similar immune response to the flu vaccine as those who received a typical flu shot, researchers report online June 27 in *Lancet*. And nearly all of the patch users described the experience as painless.

The patch eliminates the need for safe needle disposal, and since it is stable at room temperature for at least a year, it doesn't require refrigeration, unlike other vaccines. So, it could eventually end up on pharmacy shelves, making vaccination more akin to picking up aspirin than visiting a doctor. Along with possibly improving vaccination rates in the United States, the patch could make delivering vaccines in developing countries easier, the researchers say.

Myron Levine, a vaccinologist at the University of Maryland School of Medicine in Baltimore, points out that more testing of the patch is yet to come. But "what a great first start," he says. "I love the idea of not having to worry about a needle and syringe."

One side of the patch looks like a regular bandage. The other side holds a small array of 100 hard cone-shaped microneedles, each a little more than half a millimeter tall, made of polyvinyl alcohol, sugar and the vaccine.

When pushed into the back of the wrist, the microneedles penetrate the outer layer of the skin and dissolve. Mark Prausnitz, a study coauthor and chemical engineer at Georgia Tech in Atlanta, says having the patch on feels "a little like Velcro being pressed against the skin."

The researchers recruited 100 healthy adults who had not yet gotten the vaccine made for the 2014–2015 flu season. Participants either received a shot, self-applied a patch or had the patch — either with or without the vaccine — placed by a health care worker.

> "I love the idea of not having to worry about a needle and syringe."
> MYRON LEVINE

No matter how the vaccine was administered, participants experienced similar typical mild side effects such as nausea, fatigue or headache. People who got the shot reported pain at the site of injection, while those who used the microneedle patch described an itchiness.

If the patch becomes available, its ease of use might boost vaccination rates in the United States — only about 43 percent of adults were vaccinated against the flu in the 2014–2015 season. The patch also could help with mass vaccination campaigns in countries with limited resources and minimally trained personnel. To aid polio eradication efforts, a test in people of a similar patch with polio vaccine is planned, Prausnitz says. ■

BODY & BRAIN

Photosynthesis treats ailing hearts

In rats, bacteria made oxygen for blood-starved tissue

BY TINA HESMAN SAEY

Acting like miniature trees that soak up sunlight and release oxygen, photosynthetic bacteria injected into the heart may lighten the damage from heart attacks, a new study in rats suggests.

When injected into rats' hearts, the microbes restored oxygen to heart tissue after blood supply was cut off, as happens in a heart attack, researchers report June 14 in *Science Advances*.

"It reads like science fiction to me, but it's fantastic if it works," says Himadri Pakrasi, a systems biologist at Washington University in St. Louis who was not involved in the research.

The organisms, called *Synechococcus elongatus*, have been used recently to produce biofuels, but this may be the first time the cyanobacteria have ever been used in a medical setting, he says.

Other researchers also reacted enthusiastically to the study. "It's outrageous, but outrageous in a good way," says Susan Golden, who studies cyanobacteria at the University of California, San Diego. Cardiovascular scientist Matthias Nahrendorf of Massachusetts General Hospital in Boston says, "I enjoy the idea. It's really fresh."

Bringing oxygen to starved tissues is what Stanford cardiovascular surgeon Joseph Woo had in mind when he and colleagues dreamed up the plan to put light-harvesting bacteria into the heart. In a heart attack, clogged arteries or blood clots cut off blood flow to the organ. Without oxygen supplied by the blood, heart cells die.

Woo wanted a way for the heart to make its own oxygen or access another supply until doctors could open blocked vessels and restore blood flow. Plants make oxygen from carbon dioxide and sunlight, so Woo wondered, "Why not bring the tree to your heart?"

CHRISTOPHER MOORE/GEORGIA TECH

He and colleagues ground up kale and spinach to harvest chloroplasts, the organelles in plant cells that carry out photosynthesis. But the chloroplasts didn't survive outside the cells. That's when the team turned to *S. elongatus*.

The team stopped blood flow to a part of rats' hearts and after 15 minutes injected cyanobacteria or a saline solution. Oxygen in tissue with bacteria increased to about three times the levels measured right after the heart attack, similar to what saline-treated rats experienced.

That was in the dark. When researchers exposed the heart to light, rats that got the bacteria had 25 times higher oxygen levels than they did after the heart attack. Four weeks after treatment, successfully treated rats had less heart damage than untreated rodents. And blood flow out of the heart was 30 percent higher in rats treated with cyanobacteria and light than those treated with bacteria in the dark. That extra blood flow could make the difference between life and death for some patients, Woo says.

The fact that the bacteria need light to supply enough oxygen to stave off heart damage presents a difficulty if the cyanobacteria are ever to be used in people, Nahrendorf says: "It will be next to impossible to open the chest to light."

Woo says his group is working with Stanford engineers to make devices that can shine light through bones and skin to reach the heart and other deep tissues.

Injecting bacteria into the heart is also a risky proposition. But the cyanobacteria were cleared from the rats' bodies within 24 hours and didn't provoke the immune system. Some other cyanobacteria produce toxins, Golden says. "But this organism is benign."

Cyanobacteria might also supply oxygen to tissues in other diseases, such as stroke, or help preserve transplant organs, says Arnar Geirsson, a cardiovascular scientist at Yale University. ■

LIFE & EVOLUTION

Flight may have steered egg evolution

Elongated shapes are common among best avian aerialists

BY LAUREL HAMERS

The mystery of why birds' eggs come in so many shapes has long been up in the air. Now new research suggests adaptations for flight may have helped shape the orbs.

Stronger fliers tend to lay eggs that are more elongated, researchers report in the June 23 *Science*. The finding comes from the first large analysis of the way egg shape varies across bird species.

"Eggs fulfill such a specific role in birds — the egg is designed to protect and nourish the chick. Why there's such diversity in form when there's such a set function was a question that we found intriguing," says Mary Caswell Stoddard, a biologist at Princeton University.

Previous studies have suggested many possible advantages for different shapes. Perhaps cone-shaped eggs are less likely to roll out of cliff-dwelling birds' nests; spherical eggs might be more resilient to damage. But no one had tested such ideas across a wide spectrum of birds.

Stoddard and colleagues analyzed eggs from 1,400 species, which the team says represent about 14 percent of known bird species. The researchers boiled each egg down to its two-dimensional silhouette and used an algorithm to describe each egg using two variables: how elliptical versus spherical the egg is and how asymmetrical it is.

The team looked at the way these two traits vary across the bird family tree. One pattern jumped out: Species that are stronger fliers, as measured by wing shape, tend to lay more elliptical or asymmetrical eggs.

L. Mahadevan, a study coauthor and Harvard mathematician and biologist, notes that the data show only an association, but the researchers propose one possible explanation: Adapting to flight streamlined bird bodies, perhaps also narrowing the reproductive tract. That narrowing would have limited the width of an egg that a female could lay. But since eggs provide nutrition, shrinking them too much would deprive the developing chick. Elongated eggs might have been a compromise that kept egg volume up without increasing girth, says Stoddard. Asymmetry can increase egg volume in a similar way.

Testing a causal link between flight ability and egg shape is tough, says Claire Spottiswoode, a zoologist at the University of Cambridge. Still, the evidence is compelling, she says. "It's a very plausible argument."

Santiago Claramunt, an ornithologist at the Royal Ontario Museum in Toronto, is less convinced. "Streamlining in birds is determined more by plumage than the shape of the body — high performing fliers can have rounded, bulky bodies," he says, which wouldn't give elongated eggs the same advantage.

Indeed, some orders of birds showed a stronger link between flying and egg shape than others. And while other factors — like where birds lay their eggs — weren't related to egg shape across birds as a whole, they could be important in certain branches of the bird family tree. ■

Bird eggs vary greatly in shape. Flying ability may help explain this diversity. Species that are better fliers typically have more elongated or asymmetrical eggs, an analysis of nearly 50,000 eggs finds.

HARVARD MUSEUM OF COMPARATIVE ZOOLOGY

LIFE & EVOLUTION

Flower hosts its own war of the sexes

Conflict arises over what's best for male versus female parts

The male and female organs in each bloom of starry campion flowers are locked in an evolutionary battle over parenthood.

BY SUSAN MILIUS

PORTLAND, ORE. — Petals of wildflowers called starry campions may be a pretty little battleground for a skirmish between the plant's male and female parts.

As is common in flowers, each *Silene stellata* bloom forms both male and female sex organs. After measuring petal variation between plants and tracking parenthood of seeds, Juannan Zhou suspected a sexual tug-of-war.

Flowers with greater male success in spreading pollen across a wildflower patch and siring seeds tended toward longer and narrower petals, Zhou reported June 26 at the Evolution 2017 meeting. Yet plants that did especially well by their female organs, maturing abundant seeds in their own ovaries, tended toward wider and shorter petals.

Zhou, now at Cold Spring Harbor Laboratory in New York, pieced together the story while working in a fenced-in plot of wild campions in Virginia. During two summers, he tracked floral details and collected seeds. He sprouted almost 2,400 seedlings and worked out which of 227 fenced-in adults had been the father.

If a conflict smolders between what's best for male versus female functions, blossom trends linked with greater fatherhood should tilt in the opposite direction from trends linked with greater motherhood. Some traits showed no signs of conflict, but petal dimensions did.

Zhou says the contrary trends might arise from the sexes' opposite interests in visits from one of its pollinators, the *Hadena ectypa* moth. These moths do much of the pollen-carrying early in midsummer. One mothload of pollen typically fertilizes all of a flower's eggs, so from the motherhood perspective, once is enough. More than once means more risk for little benefit, because female moths leave an unwanted gift behind.

Besides sucking nectar, a female *H. ectypa* often lays an egg or two. When eggs hatch, the caterpillars chew into the flower ovary and eat seeds. Certain petal shapes, Zhou speculates, might be more attractive to moths, or perhaps more discouraging for the most destructive caterpillars to invade. But he hasn't tested how petal shape affects pollinators or pests.

From the male point of view, the loss of seeds could be more than recouped by repeated moth visits to pick up more pollen to spread to other flowers. More moths could mean many more offspring.

Evolutionary ecologist Locke Rowe of the University of Toronto welcomes the new work because data on sexual conflicts in plants — and hermaphrodites — are rare. ■

LIFE & EVOLUTION

Scientists snoop to check on kelp

Microphones could monitor marine ecosystem health

BY RACHEL EHRENBERG

BOSTON — If kelp in an underwater forest makes a sound, such noises could be used to keep tabs on ocean health.

Listening to how sound reverberates through kelp beds allows scientists to eavesdrop on environmental factors such as water temperature and photosynthetic activity, bioacoustician Jean-Pierre Hermand reported June 28 at a meeting of the Acoustical Society of America.

Kelp beds and forests, valuable ecosystems that house all sorts of marine life, may help buffer the effects of warmer and acidifying waters. But such communities are also threatened by invasive species and aren't immune to the effects of climate change, making monitoring kelp crucial, said Hermand, of the Université libre de Bruxelles in Belgium.

Hermand and colleagues set up microphones in Canoe Bay off Tasmania in Australia, where *Ecklonia radiata* kelp grows thickly. For two weeks, the team deployed an underwater device that emitted a chirp every second. The underwater microphones recorded the chirps bouncing off everything in the environment, including oxygen bubbles burbling up from kelp photosynthesis, the kelp itself and the water's surface.

More than 20 fixed sensors in the water column collected environmental data that might relate to ecosystem health, such as dissolved oxygen, pH, water temperature, salinity, photosynthetic activity and turbidity.

Then the researchers examined the acoustic data, measured in decibels of energy, alongside the measured environmental variables. Mathematical analyses revealed consistent connections between the recorded sound and the environmental factors, suggesting that eavesdropping could be a good way to monitor kelp beds, Hermand said.

While the research is preliminary, it could lead to a relatively inexpensive, efficient method for assessing the well-being of kelp beds and other marine ecosystems, says Preston Wilson, an acoustics expert at the University of Texas at Austin. Current methods, such as using satellite imagery, are expensive and don't provide much detail, while hand-conducted surveys are time-consuming and labor-intensive, Wilson says.

Instead of using a device that chirps, the ultimate goal is to learn about kelp from listening alone. "Ambient noise — that's my dream," Hermand said. ■

GENES & CELLS

Microbes reveal their inner selves

New images uncover mysterious bacterial structures

BY TINA HESMAN SAEY

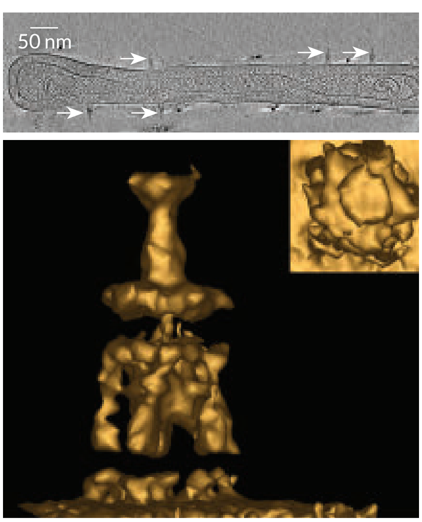
On the surface, bacteria may appear bland. But there's more going on inside than meets the eye, new studies show.

For many years, scientists thought bacteria had no internal structures and were basically "bags of enzymes," says Martin Warren, a structural and cell biologist at the University of Kent in England.

Now, a group of researchers has described a rich collection of mysterious structures and compartments within bacteria. No one knows the function of the constructs, the researchers report online June 12 in the *Journal of Bacteriology*, but they must be important for bacteria to spend so much energy building them.

A different research team presents the first atomic-scale look at a complete bacterial microcompartment in the June 23 *Science*. Microcompartments are protein shells that bacteria use to keep certain chemical reactions separate from the rest of the cell. Knowing how the microcompartment is assembled could have important applications in biotechnology and medicine, researchers say.

Appendages resembling mini Eiffel Towers (arrows in cryotomogram, top) stud the surface of *Prosthecobacter debontii* bacteria. Researchers have modeled the structure in 3-D (side view, bottom; top view, bottom inset) but don't know its function.



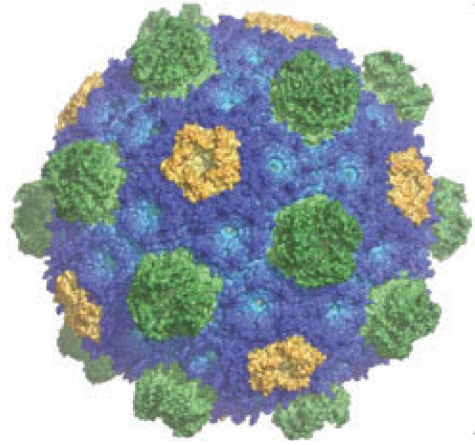
The two studies demonstrate how complex bacteria really are, says Warren, who wasn't involved in either study. "They're both fantastic pieces of work. If anybody ever thought microbiology was boring, they should have a look at this."

Since the 1950s, biologists have known that photosynthetic cyanobacteria make microcompartments, called carboxysomes, which house an important photosynthesis enzyme. About 20 percent of bacteria — even ones that don't do photosynthesis — have the genes for making similar microcompartments. Many of those tiny chambers appear only when bacteria encounter certain molecules they can use for food. For instance, some pathogenic bacteria form microcompartments to help them digest mucus from people's intestines, Warren says.

Many researchers have worked to engineer microcompartments to make drugs, industrial chemicals or biofuels. That's been difficult because scientists haven't fully understood the structures' construction. Proteins snap together to make pentagon- and hexagon-shaped units, but how the subunits come together in multisided spheres was unknown. "It's like playing with Lego building blocks but not understanding how the bricks fit together," says Danielle Tullman-Ercek, a synthetic biologist at Northwestern University in Evanston, Ill.

In addition, the individual units are curved, with a cup on one side and a bulge on the other, says medical microbiologist Michael Prentice of University College Cork in Ireland. But it wasn't clear whether the cup or the bulge went on the inside of the microcompartment.

To answer those questions, researchers led by structural biologist Cheryl Kerfeld used X-ray crystallography and cryo-electron microscopy to study microcompartment shells from the bacterium *Haliangium ochraceum*. The cups cover the shells' outsides like dimples on a golf ball, says Kerfeld,



Bacteria use protein shells to concentrate chemical reactions. Scientists have recently constructed a 3-D model that shows the shell structure in atomic-level resolution.

of Michigan State University in East Lansing and Lawrence Berkeley National Laboratory in California.

Kerfeld's team also reports in *Science* that the subunits' sides can both contact each other edge-to-edge to make flat sheets and can join up at an angle to make a curved surface. Some of the hexagon-shaped subunits stack on top of each other, giving the sphere an irregular appearance. The team is exploring how the subunits' orientation affects a compartment's function.

Microcompartments aren't bacteria's only mysterious structures. Over the last decade, structural cell biologist Grant Jensen of Caltech and colleagues have used electron cryotomography to make over 15,000 images of 88 bacterial species. The technique involves flash freezing cells so quickly that water molecules can't form crystals. Cells are preserved as they are in life, allowing researchers to see what the cells really look like on the inside and outside.

Jensen's team found structures resembling the Eiffel Tower, fishhooks, horseshoes, railroad tracks, filaments and meshes. Many different compartments within the bacterial cells or between the cell membrane and the cell wall also became apparent.

"We were discovering them faster than we could identify them," Jensen says of the structures. By publishing the images in the *Journal of Bacteriology*, he hopes crowdsourcing will help solve the mystery of what these structures do. ■

FROM TOP: M. SUTTER *ET AL*/*SCIENCE* 2017; M.J. DOBRO *ET AL*/*J. OF BACTERIOLOGY* 2017

HUMANS & SOCIETY

African farmers' kids ace willpower test

Cultural parenting styles shape how children manage self-control

BY BRUCE BOWER

Children of Nso farmers in Cameroon know how to master the marshmallow test, which has tempted away the self-control of Western kids for decades.

In a direct comparison on this delayed gratification task, Cameroonian youngsters leave middle-class German children in the dust when challenged to resist a treat in front of them while waiting for an additional goodie, a new study finds.

Of 76 Nso 4-year-olds, 53, or nearly 70 percent, managed to wait 10 minutes before eating a treat — a small local pastry called a puff-puff — in order to earn a second puff-puff, say psychologist Bettina Lamm of Osnabrück University in Germany and colleagues.

Only 35 of 125 German 4-year-olds, or 28 percent, waited for their choice of a second lollipop or chocolate bar.

The study, the first to administer the marshmallow test to non-Western kids, shows that cultural styles of child-rearing can dramatically shift how self-control develops, Lamm's team contends online June 6 in *Child Development*.

"The disparity between German and Nso cultures on the marshmallow test is huge," says psychologist Ozlem Ayduk of the University of California, Berkeley. She concurs that parenting practices among Nso farmers may at least partly boost children's ability to delay gratification.

In marshmallow tests over the last 50 years, only a minority of children in Western countries manage to wait for a second treat (*SN: 11/15/14, p. 28*). And that seems to relate to later success: Kids best able to wait display academic and social advantages decades later (*SN: 10/8/11, p. 12*).

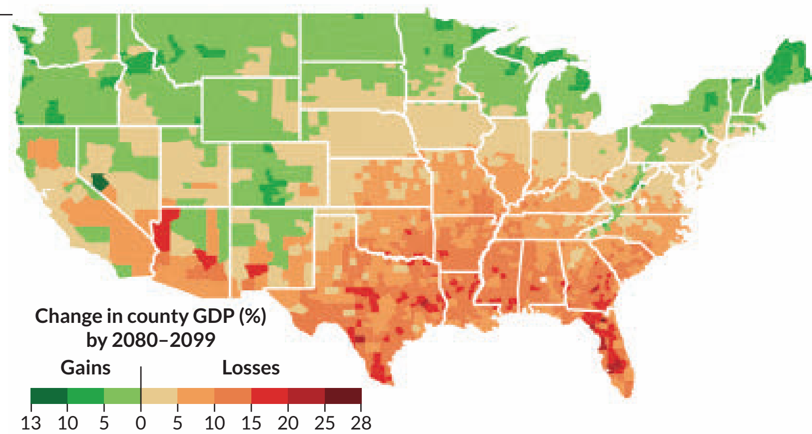
A Western cultural emphasis on raising children to be independent and to express what they want and how they feel presents challenges to self-control, Lamm says. Delaying a reward, as in the marshmallow test, stirs a frustrating feeling of powerlessness, her team proposes.

The kids in the new tests were part of a long-term study of cultural differences in memory and learning. Assessments occurred three times during the kids' first year of life and at ages 3 and 4. Among 63 of the German youngsters videotaped in play sessions with their mothers at age 9 months, those whose mothers were most lenient in letting the child determine what to do displayed the least patience on the marshmallow test at age 4, the researchers say.

Researchers have long argued that "authoritative parenting," marked by giving children freedom within specific limits, fosters self-control needed for academic and social success. German kids who waited for a second treat had mothers who dealt with them authoritatively as 9-month-olds, Lamm says.

Nso mothers typically had an authoritative parenting style, keeping their kids close and training them to keep emotions in check and to respect their elders. For 57 Nso kids recorded in play with their mothers at age 9 months, mothers consistently took the lead in organizing play activities. Nso children's self-control grew out of their mothers' authoritarian, controlling parenting style, Lamm suspects.

Ayduk notes that it's not clear whether Nso kids truly had greater self-control or if, true to farming community standards, they simply obeyed adults who asked them to wait for a second puff-puff. ■



EARTH & ENVIRONMENT

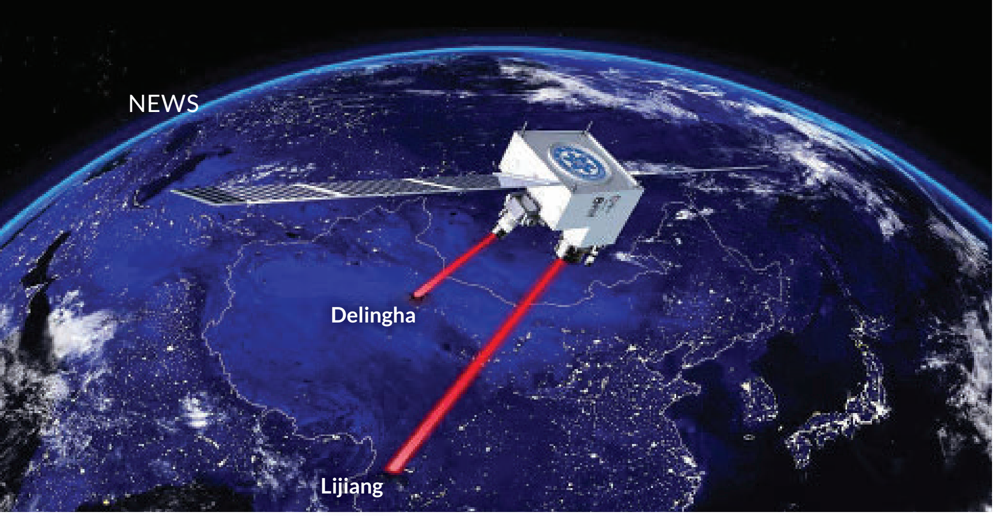
Climate change could exacerbate inequalities

Counties in the southern United States face a higher risk of economic downturn due to climate change than their northern counterparts, a new simulation predicts. Because southern regions generally host poorer populations, climate change will worsen existing wealth disparities, researchers argue in the June 30 *Science*.

Solomon Hsiang, an economist at the University of California, Berkeley, and colleagues combined several climate simulations to forecast U.S. climate until 2100, assuming greenhouse gas emissions keep ramping up. Then, using data from previous studies on how temperature and rainfall affect several economic factors — including crop yields, crime rates and energy expenditures — the team predicted how the economy of each of 3,143 counties in the United States would fare.

By the end of the century, some counties may see their gross domestic product decline by more than 20 percent; others may actually experience more than a 10 percent increase (changes in county GDPs are shown above). — *Maria Temming*

S. HSIANG *ET AL*/*SCIENCE* 2017



Using the quantum-communications satellite known as Micius (illustrated), researchers successfully sent entangled photons to two distant cities in China. The result paves the way for a future worldwide quantum network.

MATTER & ENERGY

Quantum satellite sets distance record

Entangled photons were sent to cities 1,200 kilometers apart

BY EMILY CONOVER

Particles of light born in space have connected two cities via a quantum link about 10 times longer than any created before.

A quantum-communications satellite beamed photons to Earth, separating them by more than 1,200 kilometers. The feat showed that the particles of light can retain a strange type of interconnectedness, known as quantum entanglement, even when flung to opposite ends of a country, researchers from China report in the June 16 *Science*. The previous distance record was about 100 kilometers (*SN: 6/30/12, p. 10*). Launched in 2016, the one-of-a-kind satellite is laying the groundwork for a space-based network of quantum communication.

"It's a huge achievement for quantum entanglement and quantum science," says physicist Thomas Jennewein of the University of Waterloo in Canada.

Scientists have previously beamed photons up to a satellite and back again, but those particles were not entangled. Until now, no one had distributed entangled particles from space.

The technique is expected to have major applications. "This experiment is really important for the development of a future quantum internet," says Anton Zeilinger, a physicist at the University of Vienna. Such a network would allow for ultrasecure communications and could connect quantum computers across the globe (*SN: 10/15/16, p. 13*).

An ethereal bond between two particles, entanglement is the most essential ingredient of a quantum network. Entangled particles can't be described independently; instead, they form one unit, even when separated by large distances. Measuring one entangled particle immediately reveals the state of the other. To perform quantum communication, scientists send entangled photons from place to place. But photons can travel only so far through air or optical fibers before the material absorbs the particles, limiting the distance over which communication is possible. In the emptiness of space, however, photons can travel much farther.

Using the satellite, the researchers beamed intertwined photon pairs down to the cities of Delingha in northern China and Lijiang in southern China. There, telescopes aimed at the satellite detected the particles. To confirm that the particles were entangled, and that the weird qualities of quantum mechanics held, the team used the photon pairs

BODY & BRAIN

Parkinson's may provoke T cells

Brain protein linked to disease triggers autoimmune response

BY AIMEE CUNNINGHAM

Bits of a protein that builds up in Parkinson's disease trigger the immune system, causing it to tag them as foreign invaders.

In a blood test, T cells became activated when exposed to the protein in about 40 percent of Parkinson's patients in a new study. This autoimmune response may contribute to disease progression, researchers report in the June 29 *Nature*.

Neurodegenerative disorders such as Parkinson's "have not really been thought of as autoimmune disorders," says David Sulzer, a neuroscientist at Columbia University and the New York State Psychiatric Institute in New York City. "The data strongly indicate that we better look at autoimmune responses as at least one of the links in the chain of developing Parkinson's."

Parkinson's patients experience tremors and slowed movement, among other symptoms. Scientists don't know exactly what causes Parkinson's, but during the disease, many nerve cells located in a brain region called the substantia nigra die. These neurons release dopamine, a chemical messenger that is sent to other parts of the brain to coordinate movement. Little blobs known as Lewy bodies, primarily made of a protein called alpha-synuclein, also build up in these neurons.

To distinguish between the body's own components and foreigners such as bacteria and viruses, certain types of immune cells capture proteins and present them to T cells. T cells have to figure out, "Is it self? Or is it nonself?" Sulzer says. In autoimmune disorders, the immune system makes an error in judgment.

Sulzer and colleagues had previously found that substantia nigra neurons that release dopamine can present proteins to T cells, if given a signal from the immune system. If the body cannot degrade alpha-synuclein properly, bits of this protein

JIAN-WEI PAN

to perform a Bell test (*SN: 9/19/15, p. 12*), which analyzes correlations between the two particles.

To do the experiment, the researchers had to update their equipment to work in space. That technological achievement is amazing, says Harald Weinfurter, a physicist at Ludwig-Maximilian University of Munich. "It's a huge step from the laboratory experiments to equipment which really works on a satellite." In space, sensitive components must deal with inhospitable conditions such as fluctuating temperatures and vibrations. Plus, to fit on the satellite, the whole package must be small and lightweight.

Detecting the photons is likewise daunting. Beacon lasers helped the researchers point the ground-based telescopes in the right direction to catch the photons as the satellite zipped past, 500 kilometers above Earth's surface. The accuracy the researchers achieved is like pinpointing a human hair on the ground from the top of the Eiffel Tower.

In follow-up experiments reported in two papers posted online at arXiv.org in early July, the researchers demonstrated two additional procedures necessary for quantum communications networks: successfully teleporting properties of land-based particles to spacefaring ones and sharing quantum encryption keys. ■

---

that build up in the neurons could end up being presented to T cells, which see the bits "as not being self," Sulzer says.

In the study, Sulzer's team tested for an immune response to two different small stretches of alpha-synuclein using blood from 67 Parkinson's patients and 36 healthy people. Parkinson's patients' T cells had a significantly higher response to the two pieces of alpha-synuclein than healthy people's T cells did.

Assuming the work can be replicated in other Parkinson's patients, says neuroscientist Andrew West of the University of Alabama at Birmingham, "the question becomes: When do these changes in immune cell activation become apparent? Early in the disease, or later?" ■

GENES & CELLS

Protein helps push petunia's scent out

Transporter molecule prevents harmful buildup of compounds

BY ASHLEY YEAGER

When it comes to smelling pretty, petunias are pretty pushy.

Instead of just letting scent compounds waft into the air, the plants use a particular molecule called a transporter protein to help move the compounds along, researchers report in the June 30 *Science*. The results could help researchers genetically engineer many kinds of plants both to attract pollinators and to repel pests and plant eaters.

"These researchers have been pursuing this transporter protein for a while," says David Clark, an expert in horticultural biotechnology and genetics at the University of Florida in Gainesville. "Now they've got it. And the implications could be big."

Plants use scents to communicate (*SN: 7/27/02, p. 56*). Scent compounds can attract insects and other organisms that spread pollen and help plants reproduce, or can repel pests and plant-eating animals. The protein examined in the new study could be used to dial the amount of scent up or down so that plants can attract more pollinators or better protect themselves. Currently unscented plants could be engineered to smell, too, giving them a better shot at reproduction and survival, Clark says.

A protein called PhABCG1 helps petunias release their scent, preventing damaging volatile organic compounds from accumulating in the plants. Flowers that make normal amounts of the protein are healthier (top) than flowers engineered to make less PhABCG1 (bottom).

F. ADEBESIN *ET AL*/*SCIENCE* 2017

Volatile organic compounds, which easily turn into gases at ambient temperatures, give plants their scents. Petunias get their sweet smell from a mix of benzaldehyde, the same compound that gives cherries and almonds their fruity, nutty scent, and phenylpropanoids, often used in perfumes.

But nice smells have a trade-off: If these volatile compounds build up inside a plant, they can damage the plant's cells.

About two years ago, study coauthor Joshua Widhalm, a horticulturist at Purdue University in West Lafayette, Ind., and colleagues used computer simulations to look at how petunias' scent compounds move. The results showed that the compounds can't move out of cells fast enough on their own to avoid damaging the plant. So the researchers hypothesized that something must be shuttling the compounds out.

In the new study, led by Purdue biochemist Natalia Dudareva, the team looked for genetic changes as the plant developed from its budding stage, which had the lowest levels of volatile organic compounds, to its flower-opening stage, with the highest levels. As flowers opened and scent levels peaked, the gene *PhABCG1* went into overdrive; levels of the protein that it makes jumped to more than 100 times higher than during the budding stage, the researchers report.

The team then genetically engineered petunias to produce 70 to 80 percent less of the PhABCG1 protein. Compared with regular petunias, the engineered ones released around half as much of the scent compounds, with levels inside the plant's cells building to double or more the normal levels. Images of the cells showed that the accumulation came with deterioration of cell membranes.

A lot of work has been done to identify the genes and proteins that generate scent compounds, Clark says. But this appears to be the first study to have identified a transporter protein to shuttle those compounds out of the cell. "That's a big deal," he says. ■

LIFE & EVOLUTION

Killer drillers got bigger over time

Shell holes show evolution of predator size outpaced prey's

Predators such as moon snails that kill by drilling through an animal's shell offer a way to test an idea about the power of enemies.

BY SUSAN MILIUS

In pumped-up sequels for scary beach movies, each predator is bigger than the last. Turns out that predators in real-world oceans may have upsized over time, too.

Attack holes in nearly 7,000 fossil shells suggest that drilling predators have outpaced their prey in evolving ever larger bodies and weapons, says paleontologist Adiël Klompmaker of the University of California, Berkeley. The ability to drill through a seashell lets predatory snails, octopuses, one-celled amoeba-like forams and other hungry beasts reach the soft meat inside despite prey armor. Millions of years later, CSI Paleontology is using these drill holes to test big evolutionary ideas about the power of predators.

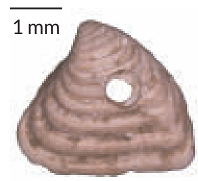
"Predators got bigger — three words!" is Klompmaker's bullet point for the work. Over the last 450 million years or so, drill holes have grown in average size from 0.35 millimeters to 3.25 millimeters, Klompmaker and colleagues report in the June 16 *Science*. Larger holes generally mean larger attackers, the researchers say after looking at 556 modern drillers and the sizes of their attack holes.

Prey changed over millennia, too, but there's no evidence for a shift in body size. The ratio of drill-hole size to prey size became 67 times greater over time, the researchers conclude.

It's "the rise of the bullies," says study coauthor Michal Kowalewski of the University of Florida in Gainesville.

These data on shell holes allow researchers to test a key part of what's called the escalation hypothesis. In 1987, Geerat Vermeij proposed a top-down view of evolutionary change, where predators, competitors and other enemies growing ever more powerful drive the biggest changes in their victims. This wouldn't be so much an arms race between predators trading tit for tat with their prey as a long domination of underdogs repeatedly stomped by disproportionate menace. (Unless the prey somehow flips the relationship and can do deadly harm in return.) Vermeij, now at the University of California, Davis, and others have drawn on the concept of escalating threats to explain prey evolutionary innovations in thick shells, spines and spikes, mobility, burrowing lifestyles and toxins.

One aspect of escalation scenarios has been especially hard to test: the idea that predators can become more dangerous and a stronger evolutionary force over time. Drill holes suggesting bigger, more powerful attackers allowed a rare way of exploring the idea, Klompmaker says. He reads the deep history as showing predators escalated in size, but prey didn't.



This roughly 4-million-year-old shell shows a hole left by an attack.

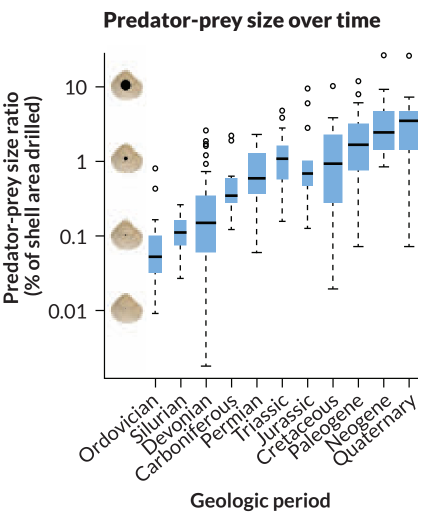
The energetics worked out, in large part, because early hard-shelled prey called brachiopods — a bit like clams but with one shell-half larger than the other — became scarcer over time, while clams and other mollusks grew abundant. Mollusks typically have more flesh than brachiopods, and prey overall grew denser on the ocean bottom. Killer drillers dining at this buffet could thus evolve bigger bodies even when prey size wasn't rising too.

Prey don't make drilling easy, Klompmaker says. An hour's work gets a typical modern predatory snail only about 0.01 to 0.02 millimeters deeper into a mollusk shell. So striking lunch could take days of effort with the thickest shells. And that's with specialty equipment: The predator alternates grinding away using a hard, rasplike driller and then switching to its accessory boring organ, which releases acids and enzymes, weakening the drilling spot for the next bout.

The role of such animal clashes in evolution has been notoriously difficult to study, says marine ecologist Nick Dulvy of Simon Fraser University in Burnaby, Canada. Nutrients, climate and other factors that don't wander off are much easier to measure. Even after a century of robust ecological study, "the discoveries that otters propped up kelp forests, triggerfishes garden coral reefs, and wolves and cougars create lush, diverse watersheds are comparatively recent," Dulvy says. Until the new drill-hole study, he could think of only one earlier batch of evidence (crabs preying on mollusks) for the long rise of predators as an evolutionary force.

The story from drill holes, Vermeij says, is "very convincing." ■

Bigger and bigger Holes drilled in shells by marine predators tended to get larger in relation to the size of the attacked shell over about the last 450 million years. This and related trends suggest predators outpaced their prey in body size.



ATOM & COSMOS

Astronomers get glimpse of star 9 billion light-years away

The most distant star ever observed has been spotted, and its light comes from across two-thirds of the universe. That puts the star 9 billion light-years away.

Patrick Kelly of the University of California, Berkeley and colleagues found the star in Hubble Space Telescope images of the galaxy cluster MACS J1149. In April and May 2016, Kelly's team saw a mysteriously fluctuating point of light in the galaxy cluster's vicinity.

Follow-up images and analyses, reported June 30 at arXiv.org, showed that the light is probably from a single bright blue star that coincidentally was behind the galaxy cluster, aligned along Hubble's line of sight. The star is visible because the galaxy cluster's gravity bent spacetime around the cluster, making it act like a cosmic magnifying glass.

The team calculated how much the star's light was stretched by its journey, a clue to its distance. Since the universe is 13.8 billion years old, and looking farther into the universe is the same as looking backward in time, that means this star's light has crossed 65 percent of the universe to reach us. The previous farthest star observed directly was just 55 million light-years away. *— Lisa Grossman*

ATOM & COSMOS

New particle relies on its charms

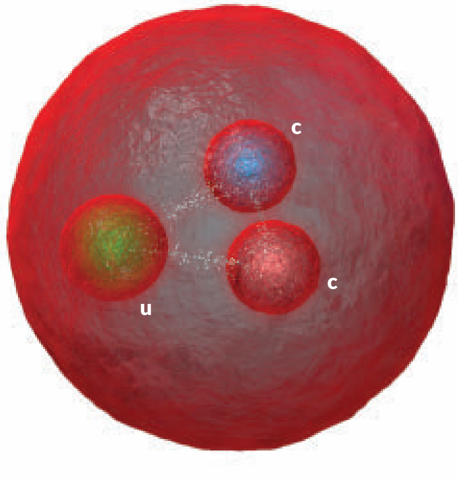
A newly discovered particle is dishing out a double dose of charm.

The newcomer is a baryon, which is composed of three smaller particles called quarks. This particular baryon has two "charm" quarks and one "up" quark. Detected by an experiment at the Large Hadron Collider at CERN, the European physics laboratory near Geneva, the baryon is the first discovered with two charm quarks. Scientists reported the find July 6 in Venice, Italy, at the European Physical Society Conference on High Energy Physics. Scientists produced the particle by ramming protons together and sifting through the aftermath.

Baryons can be composed of a variety of quark combinations, two up quarks and one charm quark, for example, or one "strange" quark and two "down" quarks. Because the charm quarks are a heavy quark variety, the new baryon should help physicists perform new types of tests of their theories of particle interactions.

Although the particle, called a doubly charmed xi baryon, is the first of its kind, its appearance is no surprise — physicists' theories predicted its existence. The particle's mass, about four times that of the proton, agreed with expectations. *— Emily Conover*

A newly discovered particle called a doubly charmed xi baryon has two heavy quarks known as charm quarks and one up quark.



DANIEL DOMINGUEZ/CERN

HUMANS & SOCIETY

Fossil tooth pushes back record of mysterious Neandertal relative

DNA retrieved from a child's worn-down fossil tooth shows the ancient Asian roots of extinct Neandertal relatives called Denisovans, researchers say.

A 10- to 12-year-old female Denisovan, represented by the tooth, lived at least 100,000 years ago, conclude evolutionary geneticist Viviane Slon of the Max Planck Institute for Evolutionary Anthropology in Leipzig, Germany, and colleagues. The tooth is at least 20,000 years older than the oldest of the three other known Denisovan fossils — a finger fragment and two teeth — the scientists report July 7 in *Science Advances*. All four specimens were unearthed in Siberia's Denisova Cave.

Mitochondrial DNA and a bit of nuclear DNA were extracted from the youngster's tooth. Mitochondrial DNA typically passes from mothers to children. Nuclear DNA is inherited from both parents.

Comparisons of the child's DNA with that of the three other Denisovans, 10 Neandertals, five ancient humans, five present-day humans, a chimp and a roughly 400,000-year-old member of the *Homo* genus from Spain enabled identification and approximate dating of the find. Previous dating of sediment layers in Denisova Cave helped to narrow down the fossil's estimated age.

Despite Denisovans having inhabited the mountainous region around Denisova Cave for tens of thousands of years, the four fossil individuals attributed to the ancient population display relatively low levels of genetic diversity, the scientists say. Lack of diversity may be due to a small Denisovan population having inhabited one part of Asia for a long time. Or perhaps Denisovans lived elsewhere in Asia and evolved more genetic diversity than observed at the cave. *— Bruce Bower*

GENES & CELLS

Modern stallions' forefathers ID'd

A few stallions from the Orient may be the sires of all modern horses.

Using genetic analyses of over 50 horse breeds, along with the pedigrees of three stallions that founded English Thoroughbreds, researchers traced the Y chromosomes of modern horses back hundreds of years. Arabian and Turkoman stallions were the source of Y chromosomes shared by all domestic stallions today, the team reports in the July 10 *Current Biology*. The three founding English Thoroughbred stallions were descendants of the now-extinct Turkoman horses and spread their Y chromosomes to many other breeds. This world domination started 647 years ago, give or take 229 years, Barbara Wallner of the University of Veterinary Medicine Vienna and colleagues calculate.

Previous studies suggested Y chromosome diversity is limited because only a few stallions were tamed and bred into domestic horses about 5,500 years ago. But a recent study showed that the winnowing of Y chromosomes happened within the last 2,000 years, long after horses were domesticated (*SN: 5/27/17, p. 10*). The new work helps pinpoint when that shift happened. *— Tina Hesman Saey*

FEATURE

SPYING ON NUCLEAR **BLASTS**

Seismologists track down clues to North Korea's underground weapons testing

By Alexandra Witze

Ears to the ground
Using seismic wave data, researchers calculated the likely locations of five nuclear tests in North Korea's Mount Mantap (satellite image shown).

S.J. GIBBONS ET AL/GEOPHYS. J. INT. 2017, GOOGLE EARTH

On September 9 of last year, in the middle of the morning, seismometers began lighting up around East Asia. From South Korea to Russia to Japan, geophysical instruments recorded squiggles as seismic waves passed through and shook the ground. It looked as if an earthquake with a magnitude of 5.2 had just happened. But the ground shaking had originated at North Korea's nuclear weapons test site.

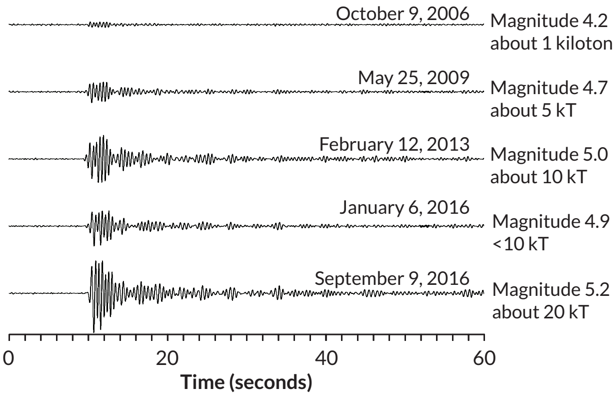
It was the fifth confirmed nuclear test in North Korea, and it opened the latest chapter in a long-running geologic detective story. Like a police examiner scrutinizing skid marks to figure out who was at fault in a car crash, researchers analyze seismic waves to determine if they come from a natural earthquake or an artificial explosion. If the latter, then scientists can also tease out details such as whether the blast was nuclear and how big it was. Test after test, seismologists are improving their understanding of North Korea's nuclear weapons program.

The work feeds into international efforts to monitor the Comprehensive Nuclear-Test-Ban Treaty, which since 1996 has banned nuclear weapons testing. More than 180 countries have signed the treaty. But 44 countries that hold nuclear technology must both sign and ratify the treaty for it to have the force of law. Eight, including the United States and North Korea, have not.

To track potential violations, the treaty calls for a four-pronged international monitoring system, which is currently about 90 percent complete. Hydroacoustic stations can detect sound waves from underwater explosions. Infrasound stations listen for low-frequency sound waves rumbling through the atmosphere. Radionuclide stations sniff the air for the radioactive by-products of an atmospheric test. And seismic stations pick up the ground shaking, which is usually the fastest and most reliable method for confirming an underground explosion.

Seismic waves offer extra information about an explosion, new studies show. One research group is exploring how local topography, like the rugged mountain where the North Korean government conducts its tests, puts its imprint on the seismic signals. Knowing that, scientists can better pinpoint where the explosions are happening within the mountain — thus improving understanding of how deep and powerful the blasts are. A deep explosion is more likely to mask the power of the bomb.

Impact of North Korea's nuclear weapons tests



Blasts get bigger Seismograms of the North Korean nuclear tests show the magnitude of shaking from each and the approximate kilotons of energy released. The 1945 Hiroshima bomb was about 15 kilotons.

Separately, physicists have conducted an unprecedented set of six explosions at the U.S. nuclear test site in Nevada. The aim was to mimic the physics of a nuclear explosion by detonating chemical explosives and watching how the seismic waves radiate outward. It's like a miniature, nonnuclear version of a nuclear weapons test. Already, the scientists have made some key discoveries, such as understanding how a deeply buried blast shows up in the seismic detectors.

The more researchers can learn about the seismic calling card of each blast, the more they can understand international developments. That's particularly true for North Korea, where leaders have been ramping up the pace of military testing since the first nuclear detonation in 2006. On July 4, the country launched its first confirmed ballistic missile — with no nuclear payload — that could reach as far as Alaska.

"There's this building of knowledge that helps you understand the capabilities of a country like North Korea," says Delaine Reiter, a geophysicist with Weston Geophysical Corp. in Lexington, Mass. "They're not shy about broadcasting their testing, but they claim things Western scientists aren't sure about. Was it as big as they claimed? We're really interested in understanding that."

Natural or not

Seismometers detect ground shaking from all sorts of events. In a typical year, anywhere from 1,200 to 2,200 earthquakes of magnitude 5 and greater set off the machines worldwide. On top of that is the unnatural shaking: from quarry blasts, mine collapses and other causes. The art of using seismic waves to tell one type of event from the others is known as forensic seismology.

Forensic seismologists work to distinguish a natural earthquake from what could be a clandestine nuclear test. In March 2003, for instance, seismometers detected a disturbance coming from near Lop Nor, a dried-up lake in western China that the Chinese government, which signed but hasn't ratified the test ban treaty, has used for nuclear tests. Seismologists needed to figure out immediately what had happened.

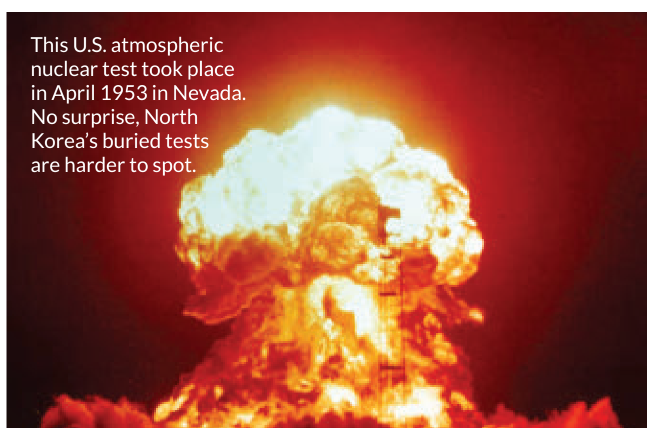
One test for telling the difference between an earthquake and an explosion is how deep it is. Anything deeper than about 10 kilometers is almost certain to be natural. In the case of Lop Nor, the source of the waves seemed to be located about six kilometers down — difficult to tunnel to, but not impossible. Researchers also used a second test, which compares the amplitudes of two different kinds of seismic waves.

Earthquakes and explosions generate several types of seismic waves, starting with P, or primary, waves. These waves are the first to arrive at a distant station. Next come S, or secondary, waves, which travel through the ground in a shearing motion, taking longer to arrive. Finally come waves that ripple across the surface, including those called Rayleigh waves.

In an explosion as compared with an earthquake, the amplitudes of Rayleigh waves are smaller than those of the P waves. By looking at those two types of waves, scientists determined the Lop Nor incident was a natural earthquake, not a secretive explosion. (Seismology cannot reveal the entire picture. Had the Lop Nor event actually been an explosion, researchers would have needed data from the radionuclide monitoring network to confirm the blast came from nuclear and not chemical explosives.)

For North Korea, the question is not so much whether the government is setting off nuclear tests, but how powerful and destructive those blasts might be. In 2003, the country withdrew from the Treaty on the Nonproliferation of Nuclear Weapons, an international agreement distinct from the testing ban that aims to prevent the spread of nuclear weapons and related technology. Three years later, North Korea announced it had conducted an underground nuclear test in Mount Mantap at a site called Punggye-ri, in the northeastern part of the country. It was the first nuclear weapons test since India and Pakistan each set one off in 1998.

By analyzing seismic wave data from monitoring stations around the region, seismologists concluded the North Korean blast had come from shallow depths, no more than a few kilometers within the mountain. That supported the North Korean government's claim of an intentional test. Two weeks later, a radionuclide monitoring station in Yellowknife,



This U.S. atmospheric nuclear test took place in April 1953 in Nevada. No surprise, North Korea's buried tests are harder to spot.

Canada, detected increases in radioactive xenon, which presumably had leaked out of the underground test site and drifted eastward. The blast was nuclear.

But the 2006 test raised fresh questions for seismologists. The ratio of amplitudes of the Rayleigh and P waves was not as distinctive as it usually is for an explosion. And other aspects of the seismic signature were also not as clear-cut as scientists had expected.

Researchers got some answers as North Korea's testing continued. In 2009, 2013 and twice in 2016, the government set off more underground nuclear explosions at Punggye-ri. Each time, researchers outside the country compared the seismic data with the record of past nuclear blasts. Automated computer programs "compare the wiggles you see on the screen ripple for ripple," says Steven Gibbons, a seismologist with the NORSAR monitoring organization in Kjeller, Norway. When the patterns match, scientists know it is another test. "A seismic signal generated by an explosion is like a fingerprint for that particular region," he says.

With each test, researchers learned more about North Korea's capabilities. By analyzing the magnitude of the ground shaking, experts could roughly calculate the power of each test. The 2006 explosion was relatively small, releasing energy equivalent to about 1,000 tons of TNT — a fraction of the 15-kiloton bomb dropped by the United States on Hiroshima, Japan, in 1945. But the yield of North Korea's nuclear tests crept up each time, and the most recent test, in September 2016, may have exceeded the size of the Hiroshima bomb.

Digging deep

For an event of a particular seismic magnitude, the deeper the explosion, the more energetic the blast. A shallow, less energetic test can look a lot like a deeply buried, powerful blast. Scientists need to figure out precisely where each explosion occurred.

Mount Mantap is a rugged granite mountain with geology that complicates the physics of how seismic waves spread. Western experts do not know exactly how the nuclear bombs are placed inside the mountain before being detonated. But satellite imagery shows activity that looks like tunnels being dug into the mountainside. The tunnels could be dug two ways: straight into the granite or spiraled around in a fishhook pattern to collapse and seal the site after a test, Frank Pabian, a nonproliferation expert at Los Alamos National Laboratory in New Mexico, said in April in Denver at a meeting of the Seismological Society of America.

Four ways to verify a nuclear weapons test

Seismic: 170 stations worldwide monitor ground shaking to identify the location, strength and nature of a seismic event.

Hydroacoustic: 11 stations listen in the oceans, where sound waves can propagate far.

Infrasound: 60 stations detect low-frequency sound waves inaudible to humans.

Radionuclide: 80 stations sniff for radioactive particles dispersed in the wind after a test.

Researchers have been trying to figure out the relative locations of each of the five tests. By comparing the amplitudes of the P, S and Rayleigh waves, and calculating how long each would have taken to travel through the ground, researchers can plot the likely sites of the five blasts. That allows them to better tie the explosions to the infrastructure on the surface, like the tunnels spotted in satellite imagery.

One big puzzle arose after the 2009 test. Analyzing the times that seismic waves arrived at various measuring stations, one group calculated that the test occurred 2.2 kilometers west of the first blast. Another scientist found it only 1.8 kilometers away. The difference may not sound like a lot, Gibbons says, but it "is huge if you're trying to place these relative locations within the terrain." Move a couple of hundred meters to the east or west, and the explosion could have happened beneath a valley as opposed to a ridge — radically changing the depth estimates, along with estimates of the blast's power.

Gibbons and colleagues think they may be able to reconcile these different location estimates. The answer lies in which station the seismic data come from. Studies that rely on data from stations within about 1,500 kilometers of Punggye-ri — as in eastern China — tend to estimate bigger distances between the locations of the five tests when compared with studies that use data from more distant seismic stations in Europe and elsewhere. Seismic waves must be leaving the test site in a more complicated way than scientists had thought, or else all the measurements would agree.

When Gibbons' team corrected for the varying distances of the seismic data, the scientists came up with a distance of 1.9 kilometers between the 2006 and 2009 blasts. The team also pinpointed the other explosions as well. The September 2016 test turned out to be almost directly beneath the 2,205-meter summit of Mount Mantap, the group reported in January in *Geophysical Journal International*. That means the blast was, indeed, deeply buried and hence probably at least as powerful as the Hiroshima bomb for it to register as a magnitude 5.2 earthquake.

Other seismologists have been squeezing information out of the seismic data in a different way — not in how far the signals are from the test blast, but what they traveled through before being detected. Reiter and Seung-Hoon Yoo, also of Weston Geophysical, recently analyzed data from two seismic stations, one 370 kilometers to the north in China and the other 306 kilometers to the south in South Korea.

The scientists scrutinized the moments when the seismic waves arrived at the stations, in the first second of the initial P waves, and found slight differences between the wiggles recorded in China and South Korea, Reiter reported at the Denver conference. Those in the north showed a more energetic pulse rising from the wiggles in the first second; the southern seismic records did not. Reiter and Yoo think this pattern represents an imprint of the topography at Mount Mantap.

"One side of the mountain is much steeper," Reiter explains. "The station in China was sampling the signal coming through the steep side of the mountain, while the southern station was seeing the more shallowly dipping face." This difference may also help explain why data from seismic stations spanning the breadth of Japan show a slight difference from north to south. Those differences may reflect the changing topography as the seismic waves exited Mount Mantap during the test.

Technicians lower an enormous canister of explosives into the ground in southern Nevada for a chemical explosion — part of the Source Physics Experiment series — to mimic the physics of nuclear blasts.

GARY STRIKER/LAWRENCE LIVERMORE NATIONAL LAB

Learning from simulations

But there is only so much scientists can do to understand explosions they can't get near. That's where the test blasts in Nevada come in.

The tests were part of phase one of the Source Physics Experiment, a $40-million project run by the U.S. Department of Energy's National Nuclear Security Administration. The goal was to set off a series of chemical explosions of different sizes and at different depths in the same borehole and then record the seismic signals on a battery of instruments. The detonations took place at the nuclear test site in southern Nevada, where between 1951 and 1992 the U.S. government set off 828 underground nuclear tests and 100 atmospheric ones, whose mushroom clouds were seen from Las Vegas, 100 kilometers away.

For the Source Physics Experiment, six chemical explosions were set off between 2011 and 2016, ranging up to 5,000 kilograms of TNT equivalent and down to 87 meters deep. The biggest required high-energy–density explosives packed into a cylinder nearly a meter across and 6.7 meters long, says Beth Dzenitis, an engineer at Lawrence Livermore National Laboratory in California who oversaw part of the field campaign. Yet for all that firepower, the detonation barely registered on anything other than the instruments peppering the ground. "I wish I could tell you all these cool fireworks go off, but you don't even know it's happening," she says.

The explosives were set inside granite rock, a material very similar to the granite at Mount Mantap. So the seismic waves racing outward behaved very much as they might at the North Korean nuclear test site, says William Walter, head of geophysical monitoring at Livermore. The underlying physics, describing how seismic energy travels through the ground, is virtually the same for both chemical and nuclear blasts.

The results revealed flaws in the models that researchers have been using for decades to describe how seismic waves travel outward from explosions. These models were developed to describe how the P waves compress rock as they propagate from large nuclear blasts like those set off starting in the 1950s by the United States and the Soviet Union. "That worked very well in the days when the tests were large," Walter says. But for much smaller blasts, like those North Korea has been detonating, "the models didn't work that well at all."

Walter and Livermore colleague Sean Ford have started to develop new models that better capture the physics involved in small explosions. Those models should be able to describe the depth and energy release of North Korea's tests more accurately, Walter reported at the Denver meeting.

A second phase of the Source Physics Experiment is set to begin next year at the test site, in a much more rubbly type of rock called alluvium. Scientists will use that series of tests to see how seismic waves are affected when they travel through fragmented rock as opposed to more coherent granite. That information could be useful if North Korea begins testing in another location, or if another country detonates an atomic bomb in fragmented rock.

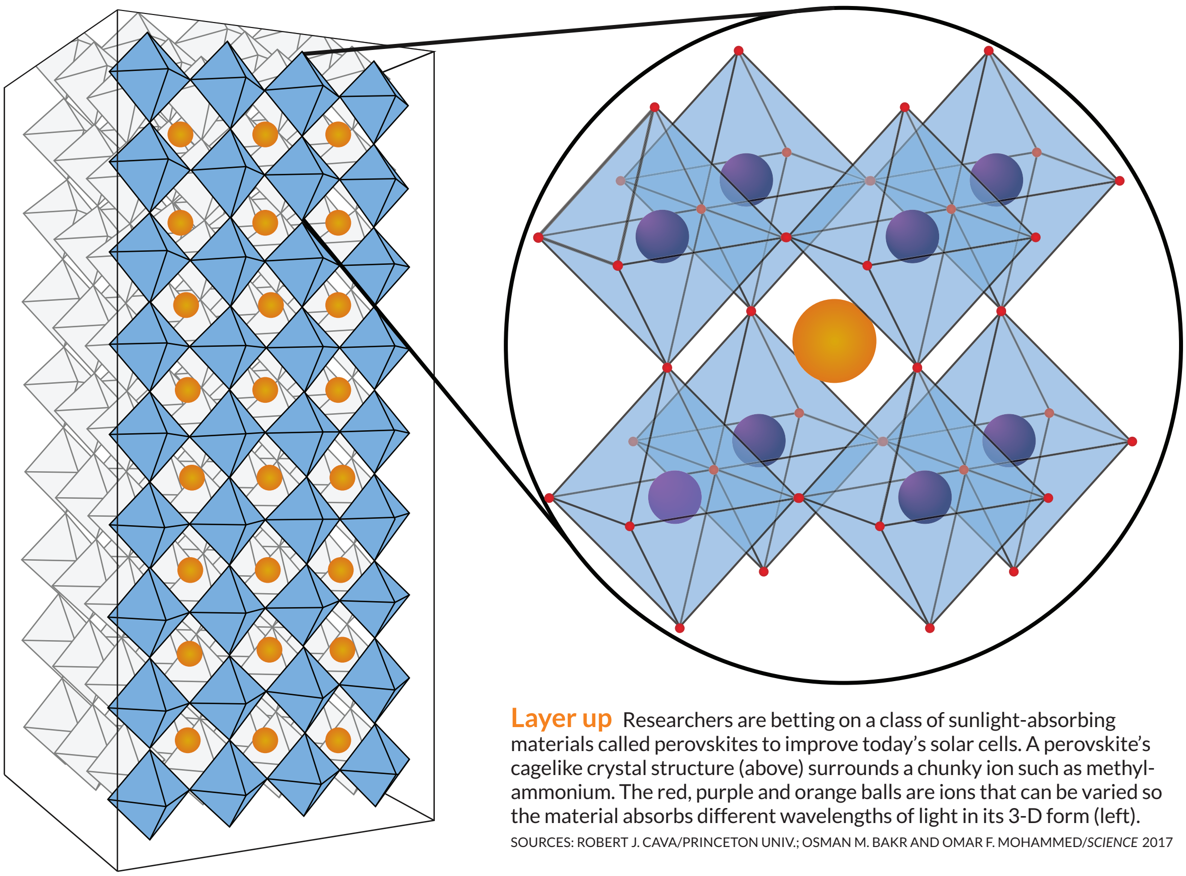
For now, the world's seismologists continue to watch and wait, to see what the North Korean government might do next. Some experts think the next nuclear test will come at a different location within Mount Mantap, to the south of the most recent tests. If so, that will provide a fresh challenge to the researchers waiting to unravel the story the seismic waves will tell.

"It's a little creepy what we do," Reiter admits. "We wait for these explosions to happen, and then we race each other to find the location, see how big it was, that kind of thing. But it has really given us a good look as to how [North Korea's] nuclear program is progressing." Useful information as the world's nations decide what to do about North Korea's rogue testing. ■

Explore more

- Comprehensive Nuclear-Test-Ban Treaty Organization: www.ctbto.org
- David Coblentz and Frank Pabian. "North Korea's Punggye-ri nuclear test site: Analysis reveals its potential for additional testing with significantly higher yields." www.38north.org/2017/03/punggye031017/

POWER UP



Layer up Researchers are betting on a class of sunlight-absorbing materials called perovskites to improve today's solar cells. A perovskite's cagelike crystal structure (above) surrounds a chunky ion such as methylammonium. The red, purple and orange balls are ions that can be varied so the material absorbs different wavelengths of light in its 3-D form (left).
SOURCES: ROBERT J. CAVA/PRINCETON UNIV.; OSMAN M. BAKR AND OMAR F. MOHAMMED/*SCIENCE* 2017

A promising material could deliver sunny days for renewable energy — if it can expand its reach

By Laurel Hamers

Tsutomu Miyasaka was on a mission to build a better solar cell. It was the early 2000s, and the Japanese scientist wanted to replace the delicate molecules that he was using to capture sunlight with a sturdier, more effective option.

So when a student told him about an unfamiliar material with unusual properties, Miyasaka had to try it. The material was "very strange," he says, but he was always keen on testing anything that might respond to light.

Other scientists were running electricity through the material, called a perovskite, to generate light. Miyasaka, at Toin University of Yokohama in Japan, wanted to know if the material could also do the opposite: soak up sunlight and convert it into electricity. To his surprise, the idea worked. When he and his team replaced the light-sensitive components of a solar cell with a very thin layer of the perovskite, the illuminated cell pumped out a little bit of electric current.

The result, reported in 2009 in the *Journal of the American Chemical Society*, piqued the interest of other scientists, too. The perovskite's properties made it (and others in the perovskite family) well-suited to efficiently generate energy from sunlight. Perhaps, some scientists thought, this perovskite might someday be able to outperform silicon, the light-absorbing material used in more than 90 percent of solar cells around the world.

Initial excitement quickly translated into promising early results. An important metric for any solar cell is how efficient it is — that is, how much of the sunlight that strikes its

T. TIBBITTS

surface actually gets converted to electricity. By that standard, perovskite solar cells have shone, increasing in efficiency faster than any previous solar cell material in history. The meager 3.8 percent efficiency reported by Miyasaka's team in 2009 is up to 22 percent this year. Today, the material is almost on par with silicon, which scientists have been tinkering with for more than 60 years to bring to a similar efficiency level.

"People are very excited because [perovskite's] efficiency number has climbed so fast. It really feels like this is the thing to be working on right now," says Jao van de Lagemaat, a chemist at the National Renewable Energy Laboratory in Golden, Colo.

Now, perovskite solar cells are at something of a crossroads. Lab studies have proved their potential: They are cheaper and easier to fabricate than time-tested silicon solar cells. Though perovskites are unlikely to completely replace silicon, the newer materials could piggyback onto existing silicon cells to create extra-effective cells. Perovskites could also harness solar energy in new applications where traditional silicon cells fall flat — as light-absorbing coatings on windows, for instance, or as solar panels that work on cloudy days or even absorb ambient sunlight indoors.

Whether perovskites can make that leap, though, depends on current research efforts to fix some drawbacks. Their tendency to degrade under heat and humidity, for example, is not a great characteristic for a product meant to spend hours in the sun. So scientists are trying to boost stability without killing efficiency.

"There are challenges, but I think we're well on our way to getting this stuff stable enough," says Henry Snaith, a physicist at the University of Oxford. Finding a niche for perovskites in an industry so dominated by silicon, however, requires thinking about solar energy in creative ways.

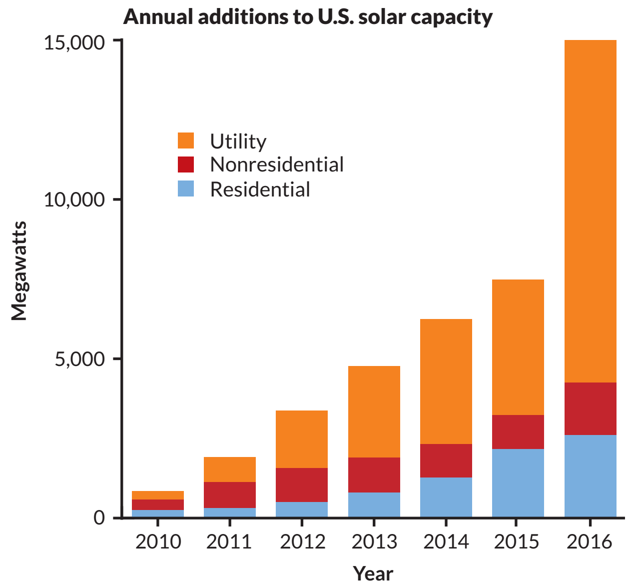
Leaping electrons

Perovskites flew under the radar for years before becoming solar stars. The first known perovskite was a mineral, calcium titanate, or $CaTiO_3$, discovered in the 19th century. In more recent years, perovskites have expanded to a class of compounds with a similar structure and chemical recipe — a 1:1:3 ingredient ratio — that can be tweaked with different elements to make different "flavors."

But the perovskites being studied for the light-absorbing layer of solar cells are mostly lab creations. Many are lead halide perovskites, which combine a lead ion and three ions of iodine or a related element, such as bromine, with a third type of ion (usually something like methylammonium). Those ingredients link together to form perovskites' hallmark cage-like pyramid-on-pyramid structure. Swapping out different ingredients (replacing lead with tin, for instance) can yield many kinds of perovskites, all with slightly different chemical properties but the same basic crystal structure.

Perovskites owe their solar skills to the way their electrons interact with light. When sunlight shines on a solar panel, photons — tiny packets of light energy — bombard the

T. TIBBITTS



Suncatchers In 2016, U.S. solar capacity rose by about 15,000 megawatts, more than in any previous year. The biggest boost was in utility-scale installations. SOURCES: SOLAR ENERGY INDUSTRIES ASSOC.; GTM RESEARCH

panel's surface like a barrage of bullets and get absorbed. When a photon is absorbed into the solar cell, it can share some of its energy with a negatively charged electron. Electrons are attracted to the positively charged nucleus of an atom. But a photon can give an electron enough energy to escape that pull, much like a video game character getting a power-up to jump a motorbike across a ravine. As the energized electron leaps away, it leaves behind a positively charged hole. A separate layer of the solar cell collects the electrons, ferrying them off as electric current.

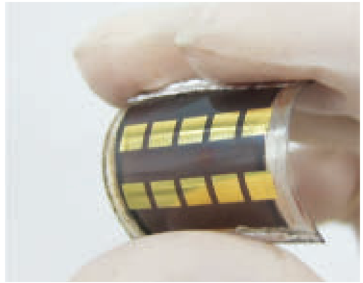
The amount of energy needed to kick an electron over the ravine is different for every material. And not all photon power-ups are created equal. Sunlight contains low-energy photons (infrared light) and high-energy photons (sunburn-causing ultraviolet radiation), as well as all of the visible light in between.

Photons with too little energy "will just sail right on through" the light-catching layer and never get absorbed, says Daniel Friedman, a photovoltaic researcher at the National Renewable Energy Lab. Only a photon that comes in with energy higher than the amount needed to power up an electron will get absorbed. But any excess energy a photon carries beyond what's needed to boost up an electron gets lost as heat. The more heat lost, the more inefficient the cell.

Because the photons in sunlight vary so much in energy, no solar cell will ever be able to capture and optimally use every photon that comes its way. So you pick a material, like silicon, that's a good compromise — one that catches a decent number of photons but doesn't waste too much energy as heat, Friedman says.

Although it has dominated the solar cell industry, silicon can't fully use the energy from higher-energy photons;

the material's solar conversion efficiency tops out at around 30 percent in theory and has hit 20-some percent in practice. Perovskites could do better. The electrons inside perovskite crystals require a bit more energy to dislodge. So when higher-energy photons come into the solar cell, they devote more of their energy to dislodging electrons and generating electric current, and waste less as heat. Plus, by changing the ingredients and their ratios in a perovskite, scientists can adjust the photons it catches. Using different types of perovskites across multiple layers could allow solar cells to more effectively absorb a broader range of photons.



Perovskite solar cells can work well even when they're very thin — and so can be printed onto plastics and other flexible materials.

Perovskites have a second efficiency perk. When a photon excites an electron inside a material and leaves behind a positively charged hole, there's a tendency for the electron to slide right back into a hole. This recombination, as it's known, is inefficient — an electron that could have fed an electric current instead just stays put.

In perovskites, though, excited electrons usually migrate quite far from their holes, Snaith and others have found by testing many varieties of the material. That boosts the chances the electrons will make it out of the perovskite layer without landing back in a hole.

"It's a very rare property," Miyasaka says. It makes for an efficient sunlight absorber.

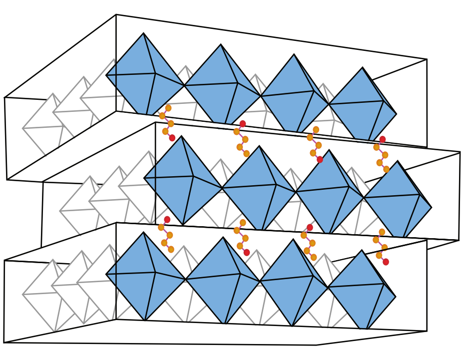
Some properties of perovskites also make them easier than silicon to turn into solar cells. Making a conventional silicon solar cell requires many steps, all done in just the right order at just the right temperature — something like baking a fragile soufflé. The crystals of silicon have to be perfect, because even small defects in the material can hurt its efficiency. The need for such precision makes silicon solar cells more expensive to produce.

Perovskites are more like brownies from a box — simpler, less finicky. "You can make it in an office, basically," says materials scientist Robert Chang of Northwestern University in Evanston, Ill. He's exaggerating, but only a little. Perovskites are made by essentially mixing a bunch of ingredients together and depositing them on a surface in a thin, even film. And while making crystalline silicon requires temperatures up to 2000° Celsius, perovskite crystals form at easier-to-reach temperatures — lower than 200°.

Flattened

Organized into thin, stackable sheets with water-repelling spacer ions in between, 2-D perovskites are more resilient against moisture and light damage than their 3-D counterparts.

SOURCE: OSMAN M. BAKR AND OMAR F. MOHAMMED/ *SCIENCE* 2017



Seeking stability

In many ways, perovskites have become even more promising solar cell materials over time, as scientists have uncovered exciting new properties and finessed the materials' use. But no material is perfect. So now, scientists are searching for ways to overcome perovskites' real-world limitations. The most pressing issue is their instability, van de Lagemaat says. The high efficiency levels reported from labs often last only days or hours before the materials break down.

Tackling stability is a less flashy problem than chasing efficiency records, van de Lagemaat points out, which is perhaps why it's only now getting attention. Stability isn't a single number that you can flaunt, like an efficiency value. It's also a bit harder to define, especially since how long a solar cell lasts depends on environmental conditions like humidity and precipitation levels, which vary by location.

Encapsulating the cell with water-resistant coatings is one strategy, but some scientists want to bake stability into the material itself. To do that, they're experimenting with different perovskite designs. For instance, solar cells containing stacks of flat, graphenelike sheets of perovskites seem to hold up better than solar cells with the standard three-dimensional crystal and its interwoven layers.

In these 2-D perovskites, some of the methylammonium ions are replaced by something larger, like butylammonium. Swapping in the bigger ion forces the crystal to form in sheets just nanometers thick, which stack on top of each other like pages in a book, says chemist Aditya Mohite of Los Alamos National Laboratory in New Mexico. The butylammonium ion, which naturally repels water, forms spacer layers between the 2-D sheets and stops water from permeating into the crystal.

Getting the 2-D layers to line up just right has proved tricky, Mohite says. But by precisely controlling the way the layers form, he and colleagues created a solar cell that runs at 12.5 percent efficiency while standing up to light and humidity longer than a similar 3-D model, the team reported in 2016 in *Nature*. Although it was protected with a layer of glass, the 3-D perovskite solar cell lost performance rapidly, within a few days, while the 2-D perovskite withered only slightly. (After three months, the 2-D version was still working almost as well as it had been at the beginning.)

Despite the seemingly complex structure of the 2-D perovskites, they are no more complicated to make than their 3-D counterparts, says Mercouri Kanatzidis, a chemist at Northwestern and a collaborator on the 2-D perovskite project. With the right ingredients, he says, "they form on their own."

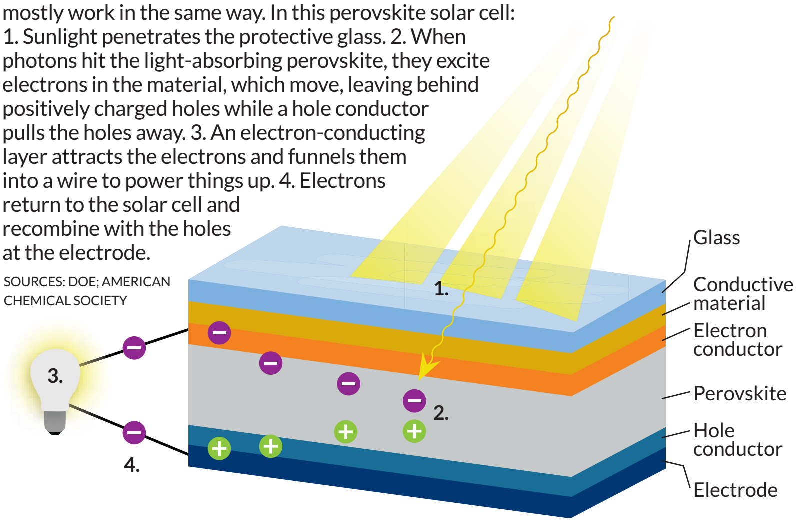
FROM TOP: T. MIYASAKA; T. TIBBITTS

His goal now is to boost the efficiency of 2-D perovskite cells, which don't yet match up to their 3-D counterparts. And he's testing different water-repelling ions to reach an ideal stability without sacrificing efficiency.

Other scientists have mixed 2-D and 3-D perovskites to create an ultra-long-lasting cell — at least by perovskite standards. A solar panel made of these cells ran at only 11 percent efficiency, but held up for 10,000 hours of illumination, or more than a year, according to research published in June in *Nature Communications*. And, importantly, that efficiency was maintained over an area of about 50 square centimeters, more on par with real-world conditions than the teeny-tiny cells made in most research labs.

Solar sandwich Solar cells have different designs but mostly work in the same way. In this perovskite solar cell: 1. Sunlight penetrates the protective glass. 2. When photons hit the light-absorbing perovskite, they excite electrons in the material, which move, leaving behind positively charged holes while a hole conductor pulls the holes away. 3. An electron-conducting layer attracts the electrons and funnels them into a wire to power things up. 4. Electrons return to the solar cell and recombine with the holes at the electrode.

SOURCES: DOE; AMERICAN CHEMICAL SOCIETY



A place for perovskites?

With boosts to their stability, perovskite solar cells are getting closer to commercial reality. And scientists are assessing where the light-capturing material might actually make its mark.

Some fans have pitted perovskites head-to-head with silicon, suggesting the newbie could one day replace the time-tested material. But a total takeover probably isn't a realistic goal, says Sarah Kurtz, codirector of the National Center for Photovoltaics at the National Renewable Energy Lab.

"People have been saying for decades that silicon can't get lower in cost to meet our needs," Kurtz says. But, she points out, the price of solar energy from silicon-based panels has dropped far lower than people originally expected. There are a lot of silicon solar panels out there, and a lot of commercial manufacturing plants already set up to deal with silicon. That's a barrier to a new technology, no matter how great it is. Other silicon alternatives face the same limitation. "Historically, silicon has always been dominant," Kurtz says.

For Snaith, that's not a problem. He cofounded Oxford Photovoltaics Limited, one of the first companies trying to commercialize perovskite solar cells. His team is developing a solar cell with a perovskite layer over a standard silicon cell to make a super-efficient double-decker cell. That way, Snaith says, the team can capitalize on the massive amount of machinery already set up to build commercial silicon solar cells.

A perovskite layer on top of silicon would absorb higher-energy photons and turn them into electricity. Lower-energy photons that couldn't excite the perovskite's electrons would pass through to the silicon layer, where they could still generate current. By combining multiple materials in this way, it's possible to catch more photons, making a more efficient cell.

That idea isn't new, Snaith points out: For years, scientists have been layering various solar cell materials in this way. But these double-decker cells have traditionally been expensive and complicated to make, limiting their applications. Perovskites' ease of fabrication could change the game. Snaith's team is seeing some improvement already, bumping the efficiency of a silicon solar cell from 10 to 23.6 percent by adding a perovskite layer, for example. The team reported that result online in February in *Nature Energy*.

Rather than compete with silicon solar panels for space on sunny rooftops and in open fields, perovskites could also bring solar energy to totally new venues.

"I don't think it's smart for perovskites to compete with silicon," Miyasaka says. Perovskites excel in other areas. "There's a whole world of applications where silicon can't be applied."

Silicon solar cells don't work as well on rainy or cloudy days, or indoors, where light is less direct, he says. Perovskites shine in these situations. And while traditional silicon solar cells are opaque, very thin films of perovskites could be printed onto glass to make sunlight-capturing windows. That could be a way to bring solar power to new places, turning glassy skyscrapers into serious power sources, for example. Perovskites could even be printed on flexible plastics to make solar-powered coatings that charge cell phones.

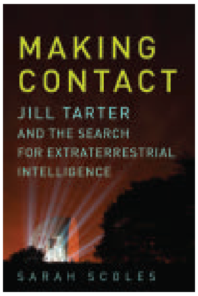
That printing process is getting closer to reality: Scientists at the University of Toronto recently reported a way to make all layers of a perovskite solar cell at temperatures below 150° — including the light-absorbing perovskite layer, but also the background workhorse layers that carry the electrons away and funnel them into current. That could streamline and simplify the production process, making mass newspaper-style printing of perovskite solar cells more doable.

Printing perovskite solar cells on glass is also an area of interest for Oxford Photovoltaics, Snaith says. The company's ultimate target is to build a perovskite cell that will last 25 years, as long as a traditional silicon cell. ■

Explore more

- National Renewable Energy Laboratory Photovoltaic Research: www.nrel.gov/pv/
- Giulia Grancini *et al*. "One-year stable perovskite solar cells by 2D/3D interface engineering." *Nature Communications*. June 2017.

T. TIBBITTS



Making Contact
Sarah Scoles
PEGASUS BOOKS, $27.95

BOOKSHELF

Astronomer hustles to find E.T.

In Carl Sagan's 1985 sci-fi novel *Contact*, a radio astronomer battles naysayers and funding setbacks to persist in her audacious plan — scanning the skies for signals from aliens. Sagan had real-life inspiration for his book (and the 1997 movie of the same name): astronomer Jill Tarter, who spearheaded the search for extraterrestrial intelligence, or SETI, for decades.

In Sagan's story, the protagonist, Ellie Arroway, detects mysterious chatter from the cosmos. Tarter had no such luck. But her story, told by journalist Sarah Scoles in *Making Contact*, still provides insights into what it means to be human in a vast universe potentially harboring other life.

Tarter began her career as a typical radio astronomer, studying mainstream topics like stars and galaxies as a Ph.D. student. But after graduating in 1975, she began to focus on SETI, poring over data from radio telescopes, searching for unnatural blips that could be a sign of an intelligent civilization. SETI researchers typically focus on radio waves because those long wavelengths can travel through our galaxy's dust without being absorbed.

Writings about SETI are prone to dreamy romanticism, but *Making Contact* admirably steers clear of excessive sentimentality. As a child gaping at the stars, Tarter wondered if creatures in the heavens were looking in our direction. Of course, Scoles notes, plenty of kids have wondered the same thing. Though Tarter's childhood musings might seem special in retrospect, they aren't what make her stand out.

Instead, Scoles — who has clear affection for her subject — highlights Tarter's tenacity. In the face of numerous obstacles, Tarter pushed the field forward, seemingly by force of will.

In a detailed portrait of how the science sausage gets made, the book follows Tarter as she faced numerous funding woes. The field of SETI, which has at various points in its history received money through NASA, is an easy target for funding cuts, with some politicians deriding it as a wasteful hunt for "little green men." Tarter, like the fictional Arroway, fought with Congress for taxpayer dollars SETI received, then scrambled for cash from other sources to keep telescopes and other equipment in operation.

> In the face of numerous obstacles, Jill Tarter pushed the field of SETI forward, seemingly by force of will.

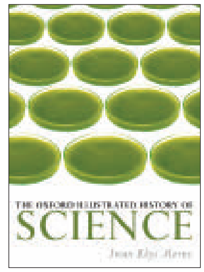
Wealthy donors kept SETI afloat — and still do. To maximize their ability to accept funding, Tarter and other SETI pioneers founded the nonprofit SETI Institute, in Mountain View, Calif., in 1984.

Throughout, Tarter somehow managed to maintain her passion for a long shot search.

Although it's a compelling story, the book stumbles in a few places, mainly minor sloppiness with physics facts, which may bother the most astute readers. (Scoles writes, for example, "Light is the only way we can learn about the universe," neglecting gravitational waves and neutrinos, both of which have revealed secrets of cosmic objects.)

Now retired, Tarter has lost her chance to follow in Arroway's fictional footsteps — she will never find any alien communiqués. But even if astronomers never hear from E.T., Tarter sees benefits in the search: SETI is an opportunity to make humankind less selfish. Just the thought that other creatures might inhabit the universe can make human squabbles seem less significant.

— *Emily Conover*



The Oxford Illustrated History of Science
Iwan Rhys Morus, ed.
OXFORD UNIV., $39.95

BOOKSHELF

Images help tell story of science

Books about the history of science, like many other histories, must contend with the realization that others have come before. Their tales have already been told. So such a book is worth reading, or buying, only if it offers something more than the same old stories.

In this case, *The Oxford Illustrated History of Science* offers most obviously an excellent set of illustrations and photographs from science's past, from various ancient Egyptian papyruses to the Hubble Space Telescope's ultradeep view of distant galaxies. Some of the images will be familiar to science fans; many others are obscure but apt; nearly all help illustrate various aspects of science's history.

And yet the pictures, while many may be worth more than 10,000 words, are still just complements to the text. Oxford attempts a novel organization for recounting the story of science: a sometimes hard-to-follow mix of chronological and topical. The first section, "Seeking Origins," has six chapters that cover ancient Mediterranean science, science in ancient China, medieval science (one chapter for the Islamic world and Europe, one for China), plus the scientific revolution and science in the Enlightenment. The second section, "Doing Science," shifts to experimenting, fieldwork, biology, cosmology, theory and science communication.

Each chapter has a different author, which has the plus of bringing distinct expertise to each subject matter but the minus of vast divergence in readability and caliber of content. Some chapters (see "Exploring Nature," on field science) are wordy, repetitive and lack scientific substance. Others ("Mapping the Universe") are compelling, engaging and richly informative. A particularly disappointing chapter on biology ("The Meaning of Life") focuses on 19th century evolution, with only a few paragraphs for the life science of the 20th and 21st centuries. That chapter closes with an odd, antiscientific tone lamenting the "huge numbers of people ... addicted to antidepressants" and complaining that modern biology (and neuroscience) "threatens to undermine traditional values of moral responsibility."

Some of the book's strongest chapters are the earliest, especially those that cover aspects of science often missing in other histories, such as science in China. Who knew that the ancient Chinese had their own set of ancient elements — not the Greeks' air, earth, water and fire, but rather wood, fire, water, soil and metal?

The first X-ray image, taken in 1895, is one of over 100 pictures in a new illustrated history of science.

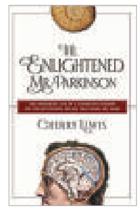
NATIONAL LIBRARY OF MEDICINE

With the book's second-half emphasis on how science was done rather than what science found out, the history that emerges is sometimes disjointed and out of order. Discussions of the modern view of the universe, which hinges on Einstein's general theory of relativity, appear before the chapter on theory, where relativity is mentioned. In fact, both relativity and quantum theory are treated superficially in that chapter, as examples of the work of theorists rather than the components of a second scientific revolution.

No doubt lack of space prevented deeper treatment of science from the last century. Nevertheless the book's merits outweigh its weaknesses. For an accessible account of the story of pre-20th century science, it's informative and enjoyable. For more recent science, you can at least look at the pictures. — *Tom Siegfried*

BOOKSHELF

The Sun
Leon Golub and Jay M. Pasachoff
Just in time for this year's total eclipse, this well-illustrated primer serves up an expert review of solar science. *Reaktion Books, $40*



The Enlightened Mr. Parkinson
Cherry Lewis
The surgeon who in the early 19th century first described the neurological disease that now bears his name had a passion for fossils and politics, this biography reveals. *Pegasus Books, $27.95*

Buy Books Reviews on the *Science News* website include Amazon.com links that generate funds for Society for Science & the Public programs.

Teachers receive $100,000 in STEM Research Grants

Society for Science & the Public is excited to announce that we have awarded $100,000 in STEM Research Grants to 23 science teachers across the country. These teachers are mentoring students, many of whom are underprivileged and underrepresented, in authentic STEM research projects. The grants help fund transportation to research facilities and the purchase of project materials such as robotics kits, DNA research equipment, microscopes, electrophoresis classroom kits, field biology collection kits and general laboratory supplies including petri dishes, sensors and pipettes.

The possibilities for meaningful STEM research opportunities afforded by this grant are endless. Thanks to the STEM Research Grant, these teachers will have the resources necessary to inspire the next generation of STEM leaders with exciting research.

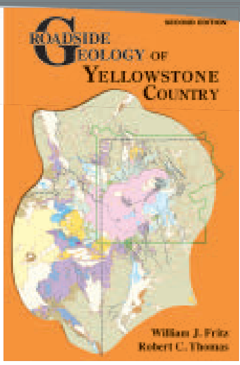
Clockwise from top: Science teacher Jesusa Merioles (left) demonstrates to her students the effectiveness of sunglasses in blocking UV rays; Peggy Veatch (right) and Michelle Wyatt (left) listen to a presentation at the Society's Research Teachers Conference in Washington D.C.; Loree Harvey (far left) presents a workshop on supporting underserved students in science research at the conference.

Congratulations to these teachers for receiving a STEM Research Grant!

Judith Barrios | Union, N.J.
Laurel Bingman | Houston, Texas
April Blaze | Haines City, Fla.
Scott Bolen | Conyers, Ga.
Cristobal Carambo | Philadelphia, Pa.
Antonio Gamboa | Pomona, Calif.
Tahnee Harrell | Miramar, Fla.
Loree Harvey | Monte Vista, Colo.
Joel Kuper | Greybull, Wyo.
Lauren Levites | Chicago, Ill.
Shawn Lowe | Alexandria, Va.
Janette Lugo-Garay | Fajardo, P.R.
Jesusa Merioles | Bronx, N.Y.
Pradip Misra | Bagdad, Ariz.
Andre Pineda | Whiteriver, Ariz.
Sherry Richardson | Washington, D.C.
Linda Sciaroni | Lynwood, Calif.
Sonia Solis | Yuma, Ariz.
Susan Swope | Deming, N.M.
Laura Tenorio | Taos, N.M.
Julie Throne | Athens, Ga.
Peggy Veatch | Eldon, Mo.
Michelle Wyatt | Columbia, S.C.

STEM RESEARCH GRANTS

GEOLOGIC ROAD TRIP OF THE MONTH



EXCERPT FROM

ROADSIDE GEOLOGY OF YELLOWSTONE COUNTRY
SECOND EDITION

328 pages • 6x9 • color
$24.00, paper • Item #240
ISBN 978-0-87842-581-5

MAMMOTH HOT SPRINGS

Mammoth Hot Springs is probably one of the most visually stunning hydrothermal features in Yellowstone. The pile of white rock can be seen from miles away, and the contrasting colors of pools and dead trees make it a favorite spot with landscape photographers. As you drive toward Mammoth Hot Springs, be sure to take Upper Terrace Drive, a one-way loop that is closed to trailers and buses. The loop is a great way to visit both the Upper and Lower terraces. A series of boardwalks provides access to the Lower Terrace.

Mammoth Hot Springs is a large hill of travertine that has been forming over thousands of years. Travertine is a finely crystalline limestone that forms in hot, warm, or cold mineral springs that are saturated with dissolved calcium carbonate. The hot springs at Mammoth are unique in depositing travertine since most others in the park deposit sinter. Hot springs and geysers both form as snowmelt and rainwater seep deep into the crust of the Earth and are heated by very hot volcanic rock. Surface water soaking into the ground can become slightly acidic due to decaying plant material and contact with hot gases charged with carbon dioxide. The hot, slightly acidic water comes in contact with many layers of rock on its journey. Beneath Mammoth it encounters limestone, which dissolves readily in the hot water, causing it to become saturated with calcium carbonate. As the heated water rises to the surface, it experiences a drop in pressure and temperature. This allows carbon dioxide gas to escape from solution (think of opening a can of soda), precipitating deposits of calcium carbonate in the hot springs.

The Upper Terrace at Mammoth Hot Springs. —Courtesy of Lyudmila Zinkova

Water spilling over a terrace at Mammoth Hot Springs.
—Courtesy of Pete Bengeyfield

Thermophiles are heat-loving microorganisms, such as bacteria and algae, that play a major role in the formation of travertine by providing sites for mineral growth and accelerating the process of mineral precipitation. Because of variations in the kinds of thermophiles and how they respond to sunlight, they are also largely responsible for the various colors of the springs. In general, colorless to yellow thermophiles grow in the hottest water, while orange, brown, and green thermophiles prefer cooler water. The colors not only reflect different species but also different responses to variations in sunlight. Pigmentation helps these species cope with the harmful effects of bright sunlight. It's a bit like sunscreen for single-celled organisms!

Fresh travertine, however, is bright white, but the longer it weathers the more it turns gray, like much of the travertine along Upper Terrace Drive. When travertine is sliced thin and observed under a microscope, the rock reveals many very thin lacy layers that record the days when photosynthetic bacteria grew and the nights when they rested. Travertine is deposited rapidly (at least in the way that geoscientists think about time). Geoscientists have reported an average rate of about 8 inches (20 cm) of rock deposited each year. The U.S. Geological Survey found 253 feet (77 m) of travertine in a hole they drilled in the Mammoth area.

The water at Mammoth appears to have a free path to the surface because the springs flow continuously and freely, although the location of the springs constantly shifts because travertine clogs the underground plumbing system. There are no geysers at Mammoth because the water is not hot enough. Apparently, hot groundwater flows here along faults from Norris Geyser Basin, about 20 miles (32 km) to the south, allowing it to cool. The Mammoth area is also much farther away from the magma chamber than the geyser basins. Drilling in the Mammoth area revealed that groundwater deep below the surface is only around 171 degrees Fahrenheit (77 degrees C). While not hot enough to boil, it can still cause severe burns. All of the bubbling in the hot springs is from carbon dioxide gas expanding at the surface, not boiling water. More information about the Mammoth area is available in the park research library at Mammoth.

JUNE 10, 2017

JUNE 24, 2017

Summer reading list

From baby brains to wasp brains, neuroscience stories fascinated readers online in June. Tales of animal evolution and physics from the *Science News* blogs also made for good summer reads. The Top 5 blog posts published in June were:

1. *Growth Curve*: "When should babies sleep in their own rooms?" by Laura Sanders (*SN Online: 6/22/17*)
2. *Science Ticker*: "New fossils shake up history of amphibians with no legs," by Susan Milius (*SN Online: 6/19/17*)
3. *Context*: "Top 10 discoveries about waves," by Tom Siegfried (*SN Online: 6/14/17*)
4. *Science Ticker*: "Facial recognition changes a wasp's brain," by Helen Thompson (*SN Online: 6/17/17*)
5. *Growth Curve*: "Babies categorize colors the same way adults do," by Laura Sanders (*SN Online: 6/1/17*)

Join the conversation

E-MAIL editors@sciencenews.org

MAIL Attn: Feedback
1719 N St., NW
Washington, DC 20036

Connect with us

Hominid hubbub

*In "Hominid roots may go back to Europe" (SN: 6/24/17, p. 9), **Bruce Bower** reported that the teeth of* Graecopithecus, *a chimp-sized primate that lived in southeastern Europe 7 million years ago, suggest it was a member of the human evolutionary family.*

"Is it appropriate to use the terms 'hominid' and 'ape' as if the two are mutually exclusive categories?" asked online reader **Tim Cliffe**. "The distinction being made is between our clade in particular and all other apes. It seems to me that 'hominids' should be described as a subset of apes, not a separate category," he wrote.

"Yes, hominids are apes," **Bower** says. "The terminology gets pretty thick in evolutionary studies, so researchers (and journalists) use some shortcuts."

Fossils of many ancient apes dating to between 25 million and 5 million years ago have been found, but the interest in this case is in a key transition to a particular kind of ape that walked upright and displayed various skeletal traits similar to traits unique to the human evolutionary family. "That's why one source in the story, Bernard Wood, wonders whether *Graecopithecus* was an apelike hominid or a hominid-like ape," **Bower** says. "But it's important to remember that hominids diverged from other, ancestral apes. So did chimps."

Science News defines "hominid" as a member of the human evolutionary family.

Laser, camera, action

*The world's fastest video camera films 5 trillion frames every second, **Ashley Yeager** reported in "A different kind of camera captures speedy actions" (SN: 6/24/17, p. 5). The camera works by flashing a laser at a subject and using a computer program to combine the still images into a video. Researchers tested the device by filming particles of light as the particles traveled a short distance.*

Online reader **JHoughton1** wondered if the researchers really filmed a light particle in their tests. "I thought light 'sometimes behaves like a wave, sometimes like a particle,' but that there isn't really any particle that's a particle in the usual sense. Is this really a picture of a 'particle' of light? A photon-as-ball-of-stuff?"

The camera captured the forward progression of a laser pulse, which is an ensemble of photons, **Yeager** says.

Photons themselves aren't "balls of stuff" on quantum scales, says physics writer **Emily Conover**. All particles, including photons, are spread out in space, propagating like waves. "Only when scientists measure or observe a photon or any other particle do they find it in one place, like the ball of stuff that people typically imagine. I think in that sense, photons are about as tangible as any other quantum particle," **Conover** says.

Bringing down the mucus house

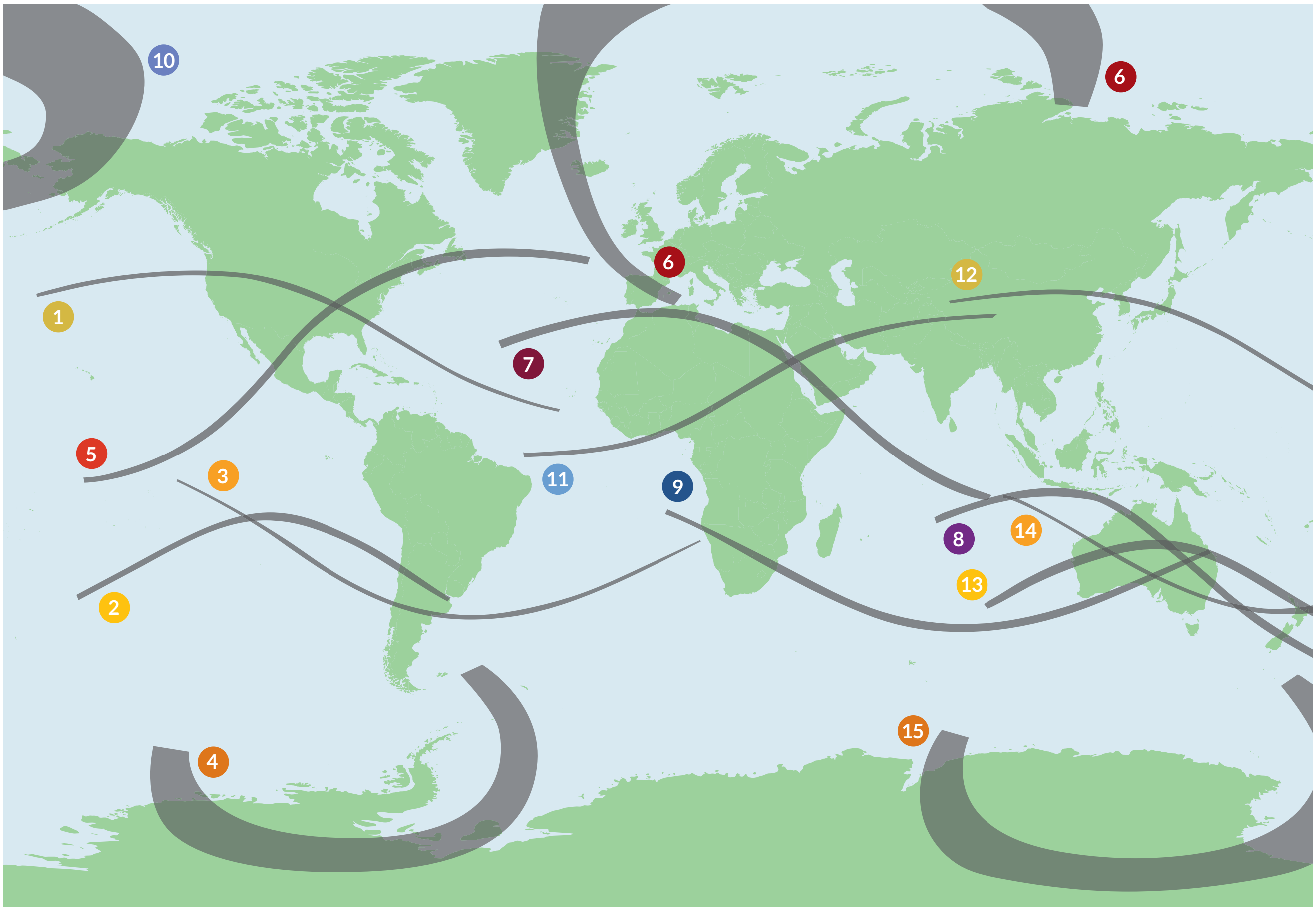
*Little-known sea animals called giant larvaceans can catch a lot of carbon in disposable mucus casings called "houses," **Susan Milius** reported in "'Mucus houses' catch sea carbon fast" (SN: 6/10/17, p. 13).*

Online reader **Robert Stenton** wondered what happens to mucus houses as they fall to the bottom of the ocean.

What happens to discarded houses isn't yet clear, **Milius** says, though researchers have proposed that the houses might carry substantial portions of carbon to life on the sea bottom. And if bits of a house fall fast enough to reach great depths, the carbon could get trapped in water masses that move around the planet for centuries before surfacing. Bits drifting down slowly may be intercepted by microbes and other debris feeders and would not end up sequestered.

Correction

In "Human noises invade wilderness" (*SN: 6/10/17, p. 14*), *Science News* incorrectly reported that official wilderness areas in the United States do not allow livestock grazing. Grazing is permitted in protected wilderness areas at pre-protection levels under the Wilderness Act of 1964, which created the National Preservation System.



Here's every total solar eclipse from now to 2040

This month's total solar eclipse won't be the last time the moon cloaks the sun's light. From now to 2040, for example, skywatchers around the globe can witness 15 such events.

Their predicted paths, shown above, aren't random scribbles. Solar eclipses occur in what's called a Saros cycle — a period that lasts about 18 years, 11 days and eight hours, and is governed by the moon's orbit. Two total solar eclipses separated by that period are almost twins — compare this year's eclipse 1 with the Sept. 2, 2035 eclipse 12, for example. They take place at roughly the same time of year, at roughly the same latitude and with the moon at about the same distance from Earth. But those extra eight hours, during which the Earth has rotated an additional third of the way on its axis, shift the eclipse path to a different part of the planet.

This cycle repeats over time, creating a family of eclipses called a Saros series. A series lasts 12 to 15 centuries and includes about 70 or more eclipses. The total eclipses of 2019 2 and 2037 13 belong to a different Saros series, so their paths also are shifted mimics. Their tracks differ in shape from 2017's, because the moon is at a different place in its orbit when it passes between Earth and the sun. Paths are wider at the poles because the moon's shadow is hitting Earth's surface at a steep angle.

The map data come from astrophysicist Fred Espenak, who is retired from NASA's Goddard Spaceflight Center in Greenbelt, Md., and retired Belgian astronomer Jean Meeus. The two have mapped solar eclipse paths from 2000 B.C. to A.D. 3000. For archaeologists, the maps help match up accounts of long-ago eclipses with actual paths. For eclipse chasers, the data are an itinerary.

"I got interested in figuring out how to calculate eclipse paths for my own use, for planning … expeditions," says Espenak, who was 18 when he witnessed his first total solar eclipse. It was in 1970, and he secured permission to drive the family car from New York to North Carolina to see the eclipse. "It's such a dramatic, spectacular, beautiful event," he says. "After it's over, you're craving to see it again." — *Emily DeMarco*

Eclipse dates

1 August 21, 2017
2 July 2, 2019
3 December 14, 2020
4 December 4, 2021
5 April 8, 2024
6 August 12, 2026
7 August 2, 2027
8 July 22, 2028
9 November 25, 2030
10 March 30, 2033
11 March 20, 2034
12 September 2, 2035
13 July 13, 2037
14 December 26, 2038
15 December 15, 2039

T. TIBBITTS; SOURCE: F. ESPENAK/GSFC/NASA

Health | EXCLUSIVE

How a Chicago Doctor Shook Up the Hearing Aid Industry with his Newest Invention

New nearly invisible digital hearing aid breaks price barrier · 90% LESS

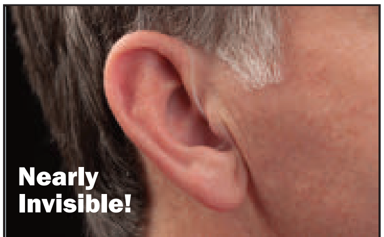
Reported by J. Page

Chicago: Board-certified physician Dr. S. Cherukuri has done it once again with his newest invention of a medical-grade, **ALL-DIGITAL, affordable hearing aid.**

This new digital hearing aid is packed with all the features of $4,000 competitors at a mere fraction of the cost. Now, most people with hearing loss are able to enjoy crystal clear, natural sound—in a crowd, on the phone, in the wind—without suffering through "whistling" and annoying background noise.

Digital Hearing Aid Outperforms Expensive Competitors

This sleek, fully programmed, light-weight, hearing aid is the outgrowth of the digital revolution that is changing our world. While demand for "all things digital" caused most prices to plunge (consider DVD players and computers, which originally sold for thousands of dollars and today can be purchased for less), the cost of a digital medical-grade hearing aid remains out of reach. Dr. Cherukuri knew that many of his patients would benefit but couldn't afford the expense of these new digital hearing aids. Generally they are *not* covered by Medicare and most private health insurance plans.



SAME FEATURES AS EXPENSIVE HEARING AID COMPETITORS

- ✓ **Mini Behind-the-Ear hearing aid with thin tubing for a nearly invisible profile**
- ✓ **Advanced Noise Reduction to make speech clearer**
- ✓ **Feedback Cancellation eliminates whistling**
- ✓ **Wide Dynamic Range Compression makes soft sounds audible and loud sounds comfortable**
- ✓ **Telecoil setting for use with compatible phones, and looped environments like churches**
- ✓ **3 Programs and Volume Dial accommodate most common types of hearing loss even in challenging listening environments**

The doctor evaluated the high priced digital hearing aids on the market, broke them down to their base components, and then created his own affordable version - called the **MDHearingAid *AIR*®** for its virtually invisible, lightweight appearance.

Affordable Digital Technology

Using advanced digital technology, the **MDHearingAid *AIR*®** automatically adjusts to your listening environment — prioritizing speech and de-emphasizing background noise. Experience all of the sounds you've been missing at a price you can afford. This doctor designed and approved hearing aid comes with a full year's supply of long-life batteries. It delivers crisp, clear sound all day long and the soft flexible ear domes are so comfortable you won't realize you're wearing them.

Try it Yourself at Home With Our 45-Day RISK-FREE Trial

Of course, hearing is believing and we invite you to try it for yourself with our -- **RISK-FREE 45-DAY HOME TRIAL.** If you are not completely satisfied, simply return it within that time period for a full refund of your purchase price.

Can a hearing aid delay or prevent dementia?

A study by Johns Hopkins and the National Institute on Aging suggests older individuals with hearing loss are significantly more likely to develop dementia over time than those who retain their hearing. They suggest that an intervention—such as a hearing aid—could delay or prevent dementia by improving hearing!

"Satisfied Buyers Agree AIR is the Best Digital Value!"

"I am hearing things I didn't know I was missing. Really amazing. I'm wearing them all the time." —Larry I., Indiana

"Almost work too well. I am a teacher and hearing much better now." —Lillian B., California

"I have used many expensive hearing aids, some over $5,000. The AIRs have greatly improved my enjoyment of life." —Sam Y., Michigan

"I would definitely recommend them to my patients with hearing loss." —Amy S., Audiologist, Indiana

For the Lowest Price *Plus* FREE SHIPPING

800-467-7990

Use Code **DE58** to get

FREE BATTERIES

for a Full Year!

GetMDHearingAid.com

MDHearingAid®

100% Money-Back Guarantee 45-DAY RISK-FREE TRIAL

Proudly Assembled in the USA from Domestic & Imported Components.

BBB A+ RATING ACCREDITED BUSINESS